Appendix A
Dam Safety Evaluation

Appendix A, Dam Safety Evaluation, includes the following information:

- **Memorandum for Record. Chatfield Reservoir Reallocation Study FR/EIS, Denver, Colorado**. This memorandum signed by the Chief of Engineering states that there is no impact to the primary flood risk management purpose of Chatfield Reservoir nor is there a change to the system flood control storage evacuation releases during a Level II flood as defined in the FR/EIS.
- **Water Supply Re-Allocation Study Dam Safety Evaluation Chatfield Dam, Littleton, CO**. This report is a geotechnical / structural dam safety evaluation of Chatfield Dam based on a potential permanent increase in the normal reservoir elevation by up to 12 feet.
- **Post-Liquefaction Stability Analyses.** This report presents the results of stability analyses performed on zones of the Chatfield Dam foundation that have been identified as susceptible to liquefaction.

CENWO-ED-GB 23 May 2013

MEMORANDUM FOR RECORD

SUBJECT: Chatfield Reservoir Reallocation Study FR/EIS, Denver, Colorado

1. Reference ER 1110-2-1156, January 2013, "Safety of Dams – Policy and Procedure" and NWDR 1110-1-3, 31 March 2003, "Modifications at Existing Corps-Owned Civil Works Projects."

2. As part of the Chatfield Reservoir Reallocation Study FR/EIS, an analysis of the effect on geotechnical, seismic, and hydrologic conditions due to reallocating 20,600 acre-feet of flood control storage to joint-use flood control and water supply storage at Chatfield Reservoir has been completed.

3. Reallocation would not impact the primary flood risk management purpose of Chatfield reservoir. During Tri-Lakes system flood control storage evacuation for Level I (small flood events), as defined in the Chatfield Reservoir Reallocation Study FR/EIS Appendix B – Tri-Lakes Water Control Plans, the reallocation of flood control storage at Chatfield slightly increases releases and affects the timing and duration of releases made from Cherry Creek and Bear Creek though the primary flood risk management purpose for Cherry Creek and Bear Creek is not affected. There is no change to system flood control storage evacuation releases during Level II (large flood events), as defined in the Chatfield Reservoir Reallocation Study FR/EIS Appendix B – Tri-Lakes Water Control Plans. Omaha District believes there are no dam safety issues that would prevent reallocation of 20,600 acre-feet of the Chatfield flood control pool.

JOHN J. BERTINO, JR., P.E.
Chief, Engineering Division

Water Supply Re-Allocation Study
Dam Safety Evaluation
Chatfield Dam
Littleton, Colorado

US Army Corps of Engineers®

Water Supply Re-Allocation Study
Dam Safety Evaluation
Chatfield Dam - Littleton, Colorado

Water Supply Re-Allocation Study
Chatfield Dam
Geotechnical / Structural Dam Safety Evaluation

EXECUTIVE SUMMARY

Presented herein is a geotechnical / structural dam safety evaluation of Chatfield Dam based on a potential permanent increase in the normal reservoir elevation by up to 12 feet. It is emphasized that this evaluation is based strictly on static loading scenarios and does not address seismic loading. It is vital to address various aspects of design and performance to assure that the proposed modifications do not impact the continued safe operation of the dam and do not pose dam safety concerns. The methodology utilized in this evaluation was to review design assumptions, evaluate instrument data compared to the design assumptions and evaluate historic performance of the project.

The requirement for a Phase I Seismic Study has been identified as a result of a Seismic Safety Review (SSR) of Chatfield Dam. A brief status of the seismic assessment is presented herein; however, seismic loading under new Corps of Engineers criteria (Phase I Study) has not been addressed in this report. The findings in this report are based strictly on normal static loading criteria.

Based strictly on a static evaluation of the project, no conditions have been identified that would prohibit adoption of the Re-Allocation Project. Installation of new piezometers located in the downstream fill, overburden and blanket drain are recommended as additional monitoring devices to assure continued safe operation of the project.

Although no dam safety concerns have been identified for the proposed reservoir loading, based on project performance and the instrumentation program, increased monitoring of the project will be required as part of the routine dam safety program to assure continued safe operation of the dam. This will include the development and implementation of a reservoir raise monitoring plan which would include additional inspection effort, instrumentation data acquisition and data analysis. The Project Surveillance Plan and Emergency Action Plan must also be updated as appropriate.

The analysis presented herein is based on a review of design assumptions, an evaluation of instrument data compared to the design assumptions and an evaluation of historic performance of the project. Any future dam safety concerns (seepage, slope stability, etc.) that may develop during/following the actual reservoir raise may have a direct bearing on the continued long term use of the re-located storage.

Water Supply Re-Allocation Study
Chatfield Dam
Geotechnical / Structural Dam Safety Evaluation

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Appendix F – Project Management Plan (PMP)

Water Supply Re-Allocation Study
Chatfield Dam
Geotechnical / Structural Dam Safety Evaluation

1.0 General. It has been proposed to raise the normal elevation of the Chatfield Reservoir by up to 12 feet, from El. 5432 feet to El. 5444 feet, for the purpose of water supply storage. The Water Re-allocation Study will actually evaluate three options, (1) no raise, (2) a five foot raise and (3) a twelve foot raise. The final adopted plan will not increase the maximum surcharge reservoir elevation. The historic maximum reservoir elevation at Chatfield Dam is 5447.58 feet. All elevations referenced hereinafter are NGVD 1929 Datum.

2.0 Purpose and Scope. The purpose of this report is to evaluate potential dam safety concerns based on a permanent increase in the reservoir elevation. The evaluation is based strictly on static loading; however, historic information on previous seismic evaluations will be presented. It is vital to address various aspects of design and performance to assure that the proposed modifications do not impact the continued safe operation of the dam and do not pose dam safety concerns. This evaluation will address the following areas of interest.

- ✓ Seismic
- ✓ Slope Protection
- ✓ Slope Stability
- ✓ Seepage
- ✓ Movement
- ✓ Structural

3.0 General Project Description. The Chatfield Dam and Reservoir Project is composed of a rolled earthfill dam, an ungated concrete spillway and stilling basin, an outlet works intake structure, two-barrel conduit and a stilling basin. A small flood detention dam, the Spring Gulch embankment, is located at the extreme right abutment of the main dam. General project drawings of the Chatfield Project are presented in Appendix A for information. Plate Nos. A-1 and A-2 present a general location plan and project plan. A list of pertinent data is as follows.

PERTINENT DATA

DRAINAGE AREA

Entire South Platte River Basin	24,030 square miles
Total above Chatfield Dam Site	3,018 square miles

RESERVOIR DATA (1991 Data)

	Elevation (feet m.s.l.)	Gross Storage (Acre-Feet)	Surface Area (Acres)
		Initial	
Maximum Surcharge Pool (Spillway Design Flood)	5521.6*	351,366	5,977
Flood Control Pool (Spillway Crest)	5500.0*	235,098	4,770
Multipurpose Pool	5432.0*	28,369	1,423
Streambed	5380.0*	0	0

* NGVD 1929

ELEVATIONS

Top of Dam*	5527.0 feet m.s.l.
Maximum Surcharge Pool (Spillway Design Flood)*	5521.6 feet m.s.l.
Spillway Crest*	5500.0 feet m.s.l.
Top of Multipurpose Pool* (Prior to Re-Allocation)	5432.0 feet m.s.l.
Top of Sediment Pool*	5426.0 feet m.s.l.

* NGVD 1929

DAM

Type	Rolled Earthfill
Maximum Height Above Riverbed	147 feet
Height Above Valley Floor	137 feet
Crest Length	13,136 feet
Fill Volume	17,255,100 cubic yards

OUTLET WORKS

Intake, Type	Tower with Access Bridge
Service Gates	
Number	2
Type	Hydraulically-Operated Slide
Size	5.5 feet X 13 feet
Emergency Gates	
Number	1
Type	Wheel-Wire Rope Hoist
Size	5.5 feet X 14.25 feet
Low-Flow Releases	
Gate Type	Gate-within-a-Gate
Size	2 feet X 2 feet
Auxiliary Conduit	
Size	72-inch diameter

Upstream Gate, Type	Butterfly
Number	1
Size	72-inch
Downstream Gate, Type	Butterfly
Number	2
Size	60-inch and 48-inch diameter
Bulkhead	
Number	1
Size	8 feet X 19.5 feet
Conduit Type	Twin Oblong
Maximum Height (inside dimension)	16.0 feet, each barrel
Maximum Width (inside dimension)	11.0 feet, each barrel
Length	756 feet
Invert Elevation, at Intake*	5385.0 feet m.s.l.
Invert Elevation, at Outlet*	5375.0 feet m.s.l.
Discharge Capacity (@ Elev. 5500.0)	8,300 cubic feet per second
Stilling Basin, type	Conventional Hydraulic Jump
Width	37 feet
Length	91 feet
Floor Elevation*	5358.0 feet m.s.l.
End Sill Elevation*	5361.0 feet m.s.l.

* NGVD 1929

SPILLWAY

Type	Ungated Chute
Bottom Width	390 feet
Crest Type	Ogee Weir
Crest Elevation*	5500.0 feet m.s.l.
Crest Length	500 feet
Stilling Basin	
Type	Conventional Hydraulic Jump
Width	390 feet
Length	154 feet
Floor Elevation*	5352.0 feet m.s.l.
End Sill Elevation*	5357.0 feet m.s.l.
Maximum Discharge	188,000 cfs @ Elev. 5521.6 feet m.s.l.*

* NGVD 1929

DOWNSTREAM CHANNEL

Capacity, maximum	5,000 c.f.s.
Width, minimum	100 feet
Length (approximate)	8 miles

WATER RIGHTS (Capacity)

	Total Decreed	D/S Requirements
Last Chance Ditch	43 c.f.s.	12 c.f.s.
Nevada Ditch	32 c.f.s.	32 c.f.s.
Denver Water Board		
City Ditch	86 c.f.s.	50 c.f.s.
Plum Creek Pump Station	34 c.f.s.	30 c.f.s.
Fish Hatchery	16 c.f.s.	16 c.f.s.

3.1 Embankment. Chatfield Dam is a rolled, zoned earthfill with a crest length of 13,136 feet, and a crest width of 30 feet. The maximum height of the embankment is 137 feet across the valley and 147 feet where it crosses the South Platte River. The embankment zoning consists of a symmetrical central impervious core with 1V on 3H side slopes; upstream and downstream random material shells; and a pervious inclined sand drain with continuous outlets adjacent to the downstream slope of the impervious core. The thickness of the pervious inclined drain is 20 feet in the valley sections and transitions to a 10 foot thickness in the abutments. An impervious cutoff trench excavated to bedrock through the pervious overburden materials joins the embankment core to provide a positive underseepage control. The outer portion of the downstream random zone includes a zone specifically for all Dawson Formation materials, which were excavated from the spillway, and outlet works excavations. The entire upstream face of the dam is protected with graded riprap. The grades (slopes) of the upstream and downstream slopes of the embankment are presented in Table Nos. 1 and 2.

Table No. 1 – Upstream Slope	
Slopes	**Elevations***
1V on 2.5H	5527.75 to 5493
1V on 5H	5493 to 5431
1V on 15H	5431 to 5420
1V on 3H	5420 to 5408
1V on 10H	5408 to Ground Surface

* NGVD 1929

Table No. 2 – Downstream Slope	
Slopes	**Elevations***
1V on 2.5H	5527.75 to 5493
1V on 5H	5493 to 5410
1V on 3H	5410 to Ground Surface

* NGVD 1929

Earthwork grading plans are presented on Plate Nos. A-3 thru A-7.

3.2 Outlet Works. The outlet works is located near the left abutment of Chatfield Dam just to the right (south east) of the spillway. The outlet works discharge channel joins the spillway discharge pilot channel approximately 1500 feet below the toe of the dam. The outlet works structures consist of an intake structure, intake structure service bridge, twin oblong outlet works conduit and an energy dissipating drop structure and stilling basin.

3.2.1 Approach Channel. The approach channel to the outlet works intake has a length of approximately 700 feet at elevation 5385.0 feet m.s.l., which is also the intake invert elevation. A U-frame structure, 31.5 feet wide with vertical walls varying in height from 24 feet to 5 feet, lines the channel for a distance of 63 feet upstream from the intake structure. The remainder of the channel is excavated with 1V on 3H side slopes and is 10-feet wide.

3.2.2 Intake Structure. The intake structure has three gated passageways that conduct water to the twin outlet works conduits. The two right passageways converge toward a conduit transition monolith in which the convergence to one passageway is completed. Each of these passageways has a service gate and emergency gate, which are controlled by hydraulic hoists. In each gate, a 2-foot by 2-foot auxiliary gate is provided to facilitate regulation of normal flows to the river. In the left passageway of the intake structure, a 6 foot diameter penstock, equipped with a butterfly valve near the upstream end, is provided to conduct releases to satisfy the downstream water rights. At the upstream end of the bellmouth entrance to each passageway are slots for bulkheads to facilitate maintenance of the gates and valves. Above the water passageways the intake is a rectangular, dry-well type structure with intermediate floors consisting of a hydraulic hoist chamber, bulkhead platform level, operating level and machine room level. An elevator and stairwells or embedded ladders furnish access between the floors. At the top of the intake structure, 142 feet above the invert, is a service deck that is accessible from the top of dam by a service bridge. A 10-foot high wall encloses the deck except for a 15 foot opening to provide access from the bridge.

3.2.3 Trash Control. Vertical concrete trash beams with horizontal circular struts are provided for trash control at the inlet of the two water passageways on the right side (looking downstream). The clear openings are approximately 5-feet by 5-feet in dimension. These trash fenders prevent trees and large floating objects from entering the water passageways but will allow passage of smaller debris, which will normally go through the intake structure and conduit without damage.

3.2.4 Conduit. Each opening in the twin oblong conduit has a width of 12.0 feet and a height of 16.0 feet. A 5.5 foot radius, semi-circular arc on top and bottom connected by 5.0 feet straight vertical side walls, forms each opening. The discharge through the right passageway is controlled by the service gates for high pools and can maintain a maximum discharge of 5,000 c.f.s. The left passageway

provides ample space for the penstock and walkway. The conduit and transition is 1,280 feet long, with a slope of 0.0076 feet/feet and invert elevations of 5385.0 feet m.s.l. and 5375.0 feet m.s.l. at the upstream and downstream ends, respectively.

3.2.5 Penstock. Three irrigation ditches were blocked off by construction of Chatfield Dam. To continue the water supply to these ditches, the left barrel of the conduit contains a 72 inch penstock, which has an independent inlet at the left side of the intake tower. The inlet includes a steel trashrack, bulkhead slots, bellmouth entrance, and a butterfly valve, which is normally operated fully opened. All bulkhead slots are the same width, thus a single bulkhead may be used for either of the two outlet works water passageways or for the penstock inlet. A manifold structure at the downstream end of penstock contains the gates and branch pipes, which distribute water to the ditches.

3.2.6 Stilling Basin. The stilling basin is a U-frame structure consisting of a drop section, 70 feet long and a level basin 88 foot long. Walls are vertical and are a maximum of 27 feet high in the level basin. The stilling basin is designed for a maximum discharge of 8,300 c.f.s. This corresponds to a pool elevation of 5,500 feet m.s.l. with both gates wide open.

3.2.7 Discharge Channel. The discharge channel connects the stilling basin with the spillway discharge pilot channel and the improved river channel. The bottom width is 100 feet. The side slopes are 1V on 3H and are riprapped for a distance of 200-feet from the stilling basin. Riprap is placed on the side slopes upstream from the end sill to guard against erosion.

3.2.8 Service Bridge. The intake service bridge is a 5-span, pre-cast, pretensioned box girder type bridge, 514'-6" long between the centerlines of bearings at the abutment and the intake tower. The bridge deck is 12'-0" wide between the 1'-3" high cast-in-place curbs on which 2'-1/2" high aluminum guard rails are mounted. The three box girders which support the bridge deck are tied together laterally by 1-1/4" diameter tensioned steel bars. The deck is constructed of cast-in-place concrete. The intermediate bridge supports are reinforced concrete bents with spread footings, approximately equally spaced. The abutment is a closed reinforced concrete structure that contains a vault for a transformer and other electrical devices.

3.3 Spillway. The chute-type spillway is located in the left abutment of the dam. The spillway consists of an ungated ogee weir, 500 feet wide and 10 feet high above the top of the approach channel slab, a chute 838 feet in length and varying in width from 500 to 390 feet, and a stilling basin 390 feet wide and 154 feet long. The stilling basin floor is 148 feet below the crest of weir. The discharge channel has a bottom width of 550-feet with 1V on 5H side slopes. From the end sill, the channel floor gradually rises about 28-feet above the stilling basin floor and then slopes gently to the river. Sandstones, siltstones, and clay-shales of the Dawson Formation underlie the spillway area.

3.3.1 Weir. The weir consists of nineteen 25 foot monoliths. A 12.5 foot section of weir is constructed integrally as a part of each abutment. The total weir length, at the centerline of the crest is an arc with a radius of 860.34 feet. The width of the weir parallel to the direction of flow is 50 feet. The crest of the weir is at elevation 5500.0 feet m.s.l. There is an 8 feet wide by 8 feet high gallery under the weir structure which houses foundation drains in the form of deep intercepting holes (PVC pipe lined) under the weir structure. These drains discharge into the gallery.

3.3.2 Abutments. On both the north and south extremities of the spillway weir, there is an abutment monolith 39.5 feet long measured normal to the direction of flow and 50 feet wide to match the upstream-downstream width of the weir. The length of each abutment monolith includes a 12.5 foot section of the weir. The spillway side face of each abutment above the crest of the weir is a vertical surface. Both abutments have a gallery entrance complete with stairs as well as ventilating and lighting systems. The abutments are identical in dimension, except they are opposite hand.

3.3.3 Approach Walls. The approach walls, which are identical in design on each side of the spillway, are cantilever type structures extending 150 feet upstream of the abutments. The walls are elliptical in alignment and were constructed in four monoliths. The upstream monolith is 25.67 feet long measured on the elliptical working line. The next three monoliths are each 52 feet long. All vertical joints contain waterstops.

3.3.4 Approach Slab. The 8-inch thick spillway approach slab extends 50-feet upstream from the face of the weir. A seat is provided for the slab at the weir on the toe of the approach walls and on the upstream cutoff structure. The joint between the slab and these structures is an expansion joint provided with waterstops. A 7 feet deep cutoff structure is provided at the upstream end of the approach slab to prevent entry of water under the slab during operation of the spillway. Beneath the slab is a drainage system that discharges into a manhole at the upstream end of slab.

3.3.5 Chute Walls. The cantilever type chute walls, which are identical in design on each side, extend downstream from the abutments a distance of 801 feet. There are waterstops in all the vertical joints, extending from the top of the wall stem to the waterstop between the base of the wall and the chute slab. The stem heights vary from about 30 feet downstream of the abutments to 14.5 feet high on the upstream 3 percent chute slope. On the 25-percent slope portion of the chute, the wall height is 13.5 feet with the exception of the downstream 134 feet where the stem varies from 13.5 feet to 47 feet in height.

3.3.6 Stilling Basin Walls. The stilling basin walls are cantilever type walls extending 154 feet downstream from the chute walls. There are waterstops included in each vertical joint from the top of the wall to the waterstop between the

base of the wall and the stilling basin slab. The top of the wall is at elevation 5399 feet m.s.l. and the stem height above the stilling basin is 47 feet. The top 3 feet of the channel face of the stem is vertical while the lower portion has a 1V on 12H batter. The chute and stilling basin walls have backfill drains and an embedded drain collector, which discharges into the wall manholes.

3.3.7 Chute and Stilling Basin Slabs. The chute slab just downstream of the weir is level, elevation 5490 feet m.s.l., and is a circular segment with a length of 34.63 feet at the slab centerline. A circular curve 8 foot long forms the transition between the level area and a 3 percent slope. The slab then extends downstream on a 3 percent slope for a distance of 283.33 feet to elevation 5481.5 feet m.s.l. In this area, spillway width converges from 500 feet at the crest centerline to 390 feet at the downstream end of the 3 percent slope. The slab slope then changes to 25 percent for a distance of 518 feet to the stilling basin, elevation 5352 feet m.s.l. The stilling basin slab extends an additional 123 foot downstream at elevation 5352 feet m.s.l. to the seat on the end sill. The width of the 25- percent portion of the chute is 390 feet, and the width of the stilling basin slab is 382.67 feet. The transition between the two widths is between the beginning of the stilling basin and a point 176 feet upstream measured horizontally on the 25 percent slope. The slab is 1.5 feet thick from the weir to Station 4+85, from which the thickness increases to 4.0 feet at Station 8+03. The remainder of the chute slab is 4.0-feet thick. In the stilling basin, the slab is 6.0 feet thick under the baffles and 9.0 feet thick at the end sill. Beneath the slabs is a system of slab and foundation drains which discharge into manholes constructed in the walls on each side of the spillway.

3.3.8 Baffles. Two rows of baffles 5-feet high extend across the width of the stilling basin. The bottom of each baffle is recessed six inches into the slab and anchored by means of No. 9 bars hooked into the slab.

4.0 Construction History. The Chatfield Dam and Reservoir Project is one unit in the comprehensive plan for flood control of the South Platte River and its tributaries within Colorado, Wyoming, and Nebraska. The project was authorized for construction by the Flood Control Act of 1950.

Construction on the Chatfield Project began in August 1967, under contract No. DACW45-68-C-0023, Earthwork - Stage I, Valley Cutoff. A list of the major construction contracts for Chatfield Dam is given below.

- **Earthwork - Stage I**, Valley Cutoff, contract number DACW45-68-C-0023 was awarded to Johnson Bros. Highway and Heavy Contractors, Inc., and D. H. Blattner and Sons, Inc., of Litchfield, Minnesota.
- **Earthwork - Stage II**, contract number DACW45-68-C-0131 was awarded to Johnson Bros. Highway and Heavy Contractors, Inc., of Litchfield, Minnesota.
- **Earthwork - Stage III**, contract number DACW45-70-C-0095 was awarded to Holloway Construction Company, of Wixom, Michigan.

- **Outlet Works**, contract number DACW45-71-C-0058 was awarded to Wietz Company Inc., of Des Moines, Iowa.
- **Spillway Structure and Intake Service Bridge**, contract number DACW45-72-C-0088 was awarded to Hensel Phelps Construction Co., of Greeley, Colorado.

Closure of Chatfield Dam was completed on 1 August 1973 under the Stage II earthwork contract. The Earthwork Stage III contract was completed in 1974. The contract for the outlet works was issued and completed during the time of the Stage III earthwork contract. All of the major facilities at Chatfield Dam were essentially completed by April 1977.

5.0 Seismic Evaluation.

5.1 Preliminary Seismic Evaluation – 1985. A Preliminary Reconnaissance Report addressing seismicity was published in June 1985. The analysis indicated that the saturated pervious overburden materials in the upstream and downstream right abutment and valley section of Chatfield Dam would be susceptible to liquefaction during postulated earthquake shaking. The preliminary evaluation concluded that in the event that these potentially unstable silty sands, silty gravelly sands and silts should liquefy during this earthquake, the seismic stability of the embankment would be questionable. It was recommended therefore to proceed with additional analysis including additional drilling, sampling and testing.

5.2 Seismic Evaluation – November 1986 (D.M. PC-44). As a result of the finding of the Preliminary Seismic Evaluation (1985), a more in-depth evaluation was conducted. The findings of this analysis concluded that the embankment materials including the sand drain would be safe against liquification. The analysis also concluded that the overburden materials (upstream and downstream) would be safe from liquefaction except for an area along the upstream toe between Station 60+00 and 95+00 and between 400 feet upstream of the embankment centerline and the embankment toe. It was also concluded that even in light of the identified liquefaction zone, the embankment would remain stable during the postulated earthquake.

5.3 Seismic Safety Review - 2002. The Omaha District performed a Seismic Safety Review (SSR) for Chatfield Dam in Fiscal Year (FY) 2002. The SSR, including a Policy Compliance and Criteria Review (PCCR), were completed in FY05. This evaluation was performed in accordance with ER 1110-2-1806 (31 July 1995) "Earthquake Design and Evaluations for Civil Works Projects" and ER 1110-2-1155 (12 September 1997) "Dam Safety Assurance Program", Appendix B "Seismic Safety Evaluation Process for Embankment Dams and Foundations".

This SSR evaluated the adequacy of the previous seismic design evaluations presented in Design Memorandum No. PC-44 "South Platte River Basin, Chatfield Dam and Lake, Colorado, Seismic Evaluation", November 1986, to determine if changes in seismicity or analytical techniques would indicate that additional detailed evaluation was warranted.

Based on the findings of the SSR and the Independent Technical Review (ITR) comments, progression of this study to a Phase I Special Study was recommended to further evaluate the seismic hazards for Chatfield Dam. The SSR also recommended that the access bridge and the bridge piers be evaluated since the gates are dependent on the power feed that runs across the bridge.

5.4 Seismic Evaluation (Phase I). The scope of the Seismic Study was expanded to determine what impacts if any the higher pool elevations (up to elevation 5444 feet msl) have on seismic stability. The seismic analysis will be published under separate cover(s).

6.0 Slope Protection – The upstream slope protection material on the embankment consists of a 12" to 26" thick layer of dumped, quarried granitic gneiss riprap underlain by a 9" layer of spalls and a 6" layer of bedding. Typical cross sections of the dam along with slope protection sections and details are presented on the General Project Plates in Appendix A. The size and gradation of the material was designed using criteria developed by the Missouri River Division from wave tank tests.

The existing multipurpose pool elevation (El. 5432 feet m.s.l.) is slightly above the transition point from the 1V:15H rocked slopes, or in some cases natural ground, to the 1V:5H slopes. The slope protection in this reach (1V:5H) consists of 20" of riprap placed on spalls and bedding. The new proposed elevation of the multipurpose pool (El. 5444 feet m.s.l.) will also be on the 1V:5H slope. Two distinct zones of horizontal riprap displacement have been identified at intermittent locations along the upstream slope during past inspections. The displacement is moderate (1 to 2 feet) and has been observed for several hundred feet along the shoreline. These displacement zones have been estimated to be between elevations 5434 and 5439 feet m.s.l. According to project personnel, the riprap was pushed up by ice-action during the winter of 1992-93. Although visual inspections indicate that 1 to 2 feet of displacement has occurred in some areas, no exposed spalls, bedding or embankment have been noted. A slight amount of displacement (1 foot or less) has also been noted near the existing normal pool line (approximate elevation 5430 to 5431 feet m.s.l.). The displaced stone has not been identified as a dam safety concern in recent Periodic or Annual Inspections. No remedial actions have been identified. These areas are monitored by project personnel on a routine basis. Raising the normal pool elevation by 5 to 12 feet should not have a direct bearing on the adequacy of the slope protection material; however, the slope protection material will continue to be monitored during routine dam safety inspections (monthly, annual, periodic,…). In addition to this, effort should be made to inspect existing areas of riprap displacement during low reservoir elevations.

7.0 Slope Stability.

7.1 General. Slope stability analyses were originally performed for three embankment sections during the design of Chatfield Dam: (1) embankment section at Station 95+00 where the embankment attains a maximum height of 137 feet and the depth of the alluvial material is approximately 55 feet; (2) the outlet works section, Station

104+34, where the embankment attains a height of approximately 117 and alluvial material is 25 feet deep; and (3) the right valley embankment section at Station 68+50 where the embankment is approximately 131 feet high but where the Dawson Formation is at the ground surface for the downstream portion of the section and 30 to 40 feet below the surface under the upstream portion of the section. The analyses consisted of investigating four cases which simulate conditions of stress during the life of the structure. The cases were: (1) end of construction; (2) sudden drawdown; (3) partial pool and (4) steady state seepage. Detailed information on the various cases analyzed during design is presented in Appendix B, Plate Nos. B-1 thru B-7.

7.2 Method of Analysis. The sliding wedge method was used for the stability analyses. The factors of safety in the analyses were defined as the ratio of the available shear strength to the average necessary to maintain equilibrium.

7.3 Summary of Results. The results of the original stability analyses performed during the design stage of Chatfield Dam are presented in Table No. 3. The results of the stability analysis (original design) based on seismic loading are presented for information only. Slope stability from seismic loadings is fully addressed under cover(s).

Table No. 3 - Slope Stability Analysis Results *

Case	Location	Critical Reservoir Elevation	Critical Factor of Safety			
			Normal		Earthquake	
			Actual	Req.**	Actual	Req.**
End of construction (u/s)	Sta. 95+00	NA	2.62	1.3	1.82	1.0
End of construction (d/s)	Sta. 95+00	NA	2.53	1.3	1.62	1.0
Partial pool (u/s)	Sta. 95+00	5460	1.49	1.5	1.04	1.0
Partial pool (u/s)	Sta. 104+35	5435-5450	1.46	1.5	0.90	1.0
Sudden drawdown (u/s)	Sta. 95+00	5500	1.33	1.2	0.92	1.0
Sudden drawdown (u/s)	Sta. 95+00	5521.6	1.23	1.0	na	na
Steady state seepage (d/s) - Conventional	Sta. 95+00	5500	1.43	1.5	.86	1.0
Steady state seepage (d/s) – At Rest pressures	Sta. 95+00	5335	1.13	-	-	-
Steady state seepage (d/s)	Sta. 104+35	5500	1.58	1.5	0.92	1.0
Steady state seepage (d/s)	Sta. 68+50	5500	1.62	1.5	0.94	1.0

* Documented in the Embankment Criteria and Performance Report, April 1980
** Based on requirements presented in EM 1110-2-1902

End of Construction, Station 95+00 - Plate No. B-1 presents the "end of construction case" (upstream & downstream) at Station 95+00. Adequate (above minimum required) factors of safety were obtained for these cases.

Partial Pool, Station 95+00 - Plate No. B-2 presents the upstream slope partial pool analysis at Station 95+00. The analysis produced a minimum (critical) factor of safety of 1.49 at pool elevation 5460 feet m.s.l. with the failure plane in the random fill. The minimum required factor of safety is 1.50. According to the analysis, the factor of safety increased both above and below this critical pool elevation (5460 feet m.s.l.) as shown on Plate No. B-2. According to the analysis, the factor of safety would be at or above the minimum required 1.5 value for a pool elevation of 5444 feet m.s.l.

Sudden Drawdown, Station 95+00 - Plate No. B-3 presents the results of the sudden drawdown analysis of the upstream slope at Station 95+00. Sudden draw-down stability (upstream slope) was evaluated for both the spillway pool (El. 5500 feet m.s.l.) and the maximum surcharge pool (El. 5521.6 feet m.s.l.). The minimum calculated factor of safety starting with a spillway pool (El.5500 feet m.s.l.) was 1.33 while the factor of safety at a surcharge pool (El. 5521.6 feet m.s.l.) was 1.23. The required factors of safety in these cases are 1.2 for pools starting at the spillway crest (5500 feet m.s.l.) and 1.0 for the maximum pool elevation (5521.6 feet m.s.l.). The analysis was performed using a conservation pool of El. 5426 feet m.s.l. whereas the actual conservation pool elevation (prior to a pool raise associated with the Re-Allocation Study) is El. 5432 feet m.s.l., six feet above what was used. This would make the analysis more conservative. The re-allocation study assumes an increase in the conservation pool elevation of up to 12 feet. This would be 18 feet above the water level used in the original design analysis (El. 5426 feet m.s.l.). Based on the conservative strengths assumed in design (as documented in the Embankment Criteria & Performance Report and discussed hereinafter), the factor of safety of 1.23 (1.0 required as minimum) at the lower conservation pool of El. 5426 feet m.s.l. and the increase in the conservation pool elevation, it is felt that the dam would have an adequate factor of safety for sudden drawdown.

Historic analysis (design stage) was based on USACE guidance available at that time and did not consider transient seepage conditions. Based on the conservative strengths assumed in design (as documented in the Embankment Criteria & Performance Report and other documents) higher conservation pool, and design calculated factor of safety of 1.23 (1.0 required as minimum), additional transient analysis is not considered necessary.

Steady State Seepage, Station 68+50, 95+00 & 104+35, - The downstream slopes of the embankment were analyzed under a steady state condition at Stations 95+00, 104+35 and 68+50 using the spillway crest pool elevation (El. 5500 feet m.s.l.). Plate No. B-4 presents the steady state seepage case at Station 95+00. Plate No. B-5 presents the steady state seepage case at Station 104+35. Plate No. B-6 presents the steady state seepage case for Station 68+50. These sections were considered to

be the most critical of all the sections studied. Saturation through the embankment was assumed to be from the spillway crest pool (El. 5500 feet m.s.l.). The maximum pool elevation (El. 5521.6 feet m.s.l.) was not used in the analysis since it was considered that this pool elevation would not be maintained long enough to produce seepage equilibrium through the embankment. The downstream piezometric level was assumed to be at the top of the pervious blanket drain (elevation 5400 feet m.s.l. at Stations 95+00 & 68+50 and elevation 5420 feet m.s.l. at Station 104+35). There appears to be a conflict between various documents as to the exact elevation and thickness of the drain. It is documented in the Embankment Criteria and Performance Report that the thickness of the drain is 20 feet in the valley and 10 feet at the abutments. The drawings show 10 feet at Station 62+00 and 20 feet at Station 70+00 whereas the cross section used for the steady state seepage stability analysis (Embankment Criteria and Performance Report) at Station 68+50 shows a 10 foot drain with top elevation of 5405 feet m.s.l. It would be advantageous to verify the exact thickness of the drain.

Station 95+00 produced the lowest factor of safety for steady state seepage conditions. As shown in Table No. 3, the computed factor of safety at Station 95+00 was 1.43 for normal conditions with the critical failure plane in the Dawson Formation. This value is 0.07 below the required minimum factor of safety (1.50). The proposed Re-Allocation project would result in a maximum new normal pool elevation of 5444 feet m.s.l. This is 56 feet lower than the reservoir elevation (5500 feet m.s.l.) analyzed. The Re-Allocation will not increase the reservoir elevation analyzed in this case (5500 feet m.s.l.) and therefore the new normal pool elevation would not be expected to reduce the factor of safety calculated during design. The factors of safety at Stations 104+35 and 68+50 were 1.58 and 1.62 respectively as presented in Table No. 3 and on Plate Nos. B-5 and B-6.

Non-circular, block failure surfaces were analyzed at Station 95+00 and 68+50 with Spencer's method utilizing the 2007 version of SLOPE/W, developed by Geo-Slope International, Ltd. For the re-analysis of the steady state seepage cases, the critical slide plane and peak effective strengths were used as presented in the Embankment Criteria and Performance Report (CENWO, 1980). The intent of these re-analyses was to compare the current methodology (Spencer's method) with the method used for the original design. The results of the re-analysis of the steady seepage cases at Station 95+00 and Station 68+50 are presented in Table No. 4. These results indicate the factors of safety determined with Spencer's method exceed those factors of safety determined during the original design.

Table No. 4			
Station	Factor of Safety		
	Original	Re-Analysis	
		Janbu's Method	Spencer's Method
95+00	1.43	1.46	1.74
68+50	1.62	1.57	1.84

The difference in the Factor of Safety between the original analyses and the re-analyses using Spencer's method is due to the side force assumptions and statics of each method.

Upstream Slope Partial Pool, Station 104+35 - The upstream slope partial pool analysis (normal loading) at Station 104+35 produced a minimum factor of safety of 1.456 @ pool elevation 5435 feet m.s.l. with the failure plane in the Dawson Formation, as presented on Plate B-5. The required minimum factor of safety is 1.50. The factor of safety increased slightly both above and below this critical elevation (5435 feet m.s.l.) as shown on Plate No. B-5. According to the information presented on Plate No. B-5, the factor of safety at the proposed new normal pool elevation (5444 feet m.s.l.) would also be approximately 1.46. It is pointed out that the current normal pool elevation is 5432 feet m.s.l. and the reservoir has historically operated approximately between elevations 5428 feet m.s.l. and 5447 feet m.s.l.
Although factors of safety slightly lower than that required by Corps criteria were obtained during the original design, the analyses were considered "as adequate" because of the exceptionally conservative adopted strengths and other assumptions in the analyses. The adopted design strength of the embankment material was based on primarily the lowest strength material of all the types placed in the embankment. The bedrock was assumed to be homogeneous in strength with no allowances made for cross bed shear and the sandy and silty phases of the Dawson Formation. The value of the adopted strength of the Dawson Formation was taken as an average between the residual shear strength test values (approximately 8 degrees) and the average peak strength of 24 degrees. The resulting adopted phi value of 15 degrees for the Dawson Shale, as shown on Plate No. B-7, was considered to be very conservative.

Additional slope stability analyses including soil testing were performed for the section of embankment at the outlet works as presented in "Supplement to Design Memorandum No. PC-24, Embankment and Excavation, December 1970." The general consensus in the August 1968 Board of Consultants meeting was that the conventional wedge analysis may not be applicable where failure is assumed in the Dawson Formation. The Board discussed the potential for strain incompatibility between the Dawson Formation and the embankment materials. The new test results fell within the range of the previous test data. The additional analyses involved no change in shear strength but took into account some or all of the following: (1) apparent soft seams in the Dawson Formation and their depth relative to the slide

planes; (2) earth pressures at rest; (3) seepage pressures in the foundation shale; (4) pore pressures recorded at Fort Peck Dam which were translated to these studies; and (5) excavations of the intake and stilling basin included in some analyses. Specific cases analyzed are as follows:

End of Construction – Sta. 103+34: These studies were made assuming the following.

- Pore pressure responses in the Dawson Formation varying from 0 to 100%.
- Driving forces computed from earth pressure theory using an at-rest pressure coefficient of 0.5.
- Strengths assumed along failure plane: phi = 15 degrees & cohesion = 0

Depending on the specific assumptions in the analysis, the computed upstream slope factors of safety ranged from 1.77 to 0.81. The downstream factors of safety were approximately 0.2 higher than calculated for the upstream slope.

Steady Seepage Case – Sta. 103+34: All design strengths were the same as used in the original analysis presented in the basic design memorandum. The factors of safety computed ranged from 1.22 to 1.24. In this case the factors of safety were considered ….”satisfactory due to the relatively low adopted shear strength and other maximum conditions assumed in the analysis”[1].

Partial Pool Case – Sta. 103+34: All design strengths were the same as used in the original analysis presented in the basic design memorandum. For three pool levels analyzed, the critical pool was at elevation 5450 feet m.s.l. with a factor of safety of 1.34. In the original stability analysis, a factor of safety of 1.46 was computed for pool elevations 5435 feet m.s.l. and 5450 feet m.s.l. “A factor of safety of 1.5 usually is required for conventional type analyses; however, the lower factor of safety appears justified here due to the use of the conservative strength assumptions”[1].

Sudden Drawdown Analysis – Sta. 103+34: For the case of drawdown from pool elevation 5500 feet m.s.l. to the minimum pool elevation of 5426 feet m.s.l. using various assumptions, a factor of safety of from 0.84 to 1.0 was obtained. It was concluded that .. ”It is extremely unlikely that all of the above conditions assumed in the analyses would ever be met, that is, the assumptions used have been conservatively chosen, and as such the resulting factors of safety reflect those assumptions”.[1]

Steady Seepage – Sta. 95+00: A revised analysis of the downstream slopes of the embankment at Station 95+00 was performed using at-rest pressures. The resulting factor of safety for the “At-Rest Pressure Analysis” was 1.13. “For this condition, with all of the maximum conditions imposed in the analysis, maintaining equilibrium is considered satisfactory”.[2]

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[1] Supplement to Design Memorandum No. PC-24, Embankment and Excavation, December 1970.

[2] Design Memorandum No. PC-24, Embankment & Excavation, Dec 1968

Results of the additional studies gave factors of safety lower than those previously obtained; in some cases below equilibrium conditions (less than 1); however, it was recognized that the many different assumptions were, as a whole, extremely conservative and as a result, the factors of safety so obtained reflected those assumptions. No definite conclusions/recommendations were identified in the Supplement to Design Memorandum PC-24 other than the use of conservative assumptions; however, it was stated that this subject would be further addressed in the Board of Consultants meeting scheduled for the fall of 1971. There was very little information documented about embankment stability and/or test results in the minutes of this meeting; however, no stability concerns were identified. Author Casagrande stated in part…"On this stability analysis, I have the impression that the assumptions are certainly on the safe side…."[3]

A discussion of the current and projected piezometric levels as compared to what was assumed in the design phase (stability analysis) is presented hereinafter.

7.5 Instrumentation Review. A piezometer location plan is presented in Appendic C, Plate No. C-1. The Chatfield Dam piezometer data is presented on Plate Nos. C-2 thru C-10. Plate Nos. C-11 thru C-14 presents various cross sections exhibiting piezometeric data. Plate Nos. C-15 thru C-35 present specific detailed piezometer plots. These plots were developed to identify any potential reflection of fluctuations in the reservoir level and ultimately the effect of an increased pool loading condition (piezometeric data) if any.

The upstream piezometric levels including data from piezometers located in the core are fairly responsive to the reservoir elevation and in some cases there is minimal headloss. Based on this piezometer data along with data projections as discussed hereinafter, it appears that the piezometric levels in both the upstream area and the core are/will be very similar to those assumed in the design (stability analysis).

The downstream piezometers are affected by the pool to a much lesser degree than the upstream and core piezometers as expected. The piezometer levels in the downstream bedrock (Dawson Formation) are currently at or below the elevation assumed in the steady state stability analysis at Stations 68+50, 95+00 and 104+35. Based on the relationship with pool fluctuations, it appears that there are potentially three critical downstream piezometers that include instruments numbers 504A, 505B, and 561. Piezometer 504A is a pneumatic pressure cell located at Station 68+90, 195 feet downstream. Piezometer 505B is a pneumatic pressure cell located at Station 68+90, approximately 400 feet downstream. Piezometer 561 is an open tube device located at Station 93+00, approximately 300 feet downstream. Data plots for these instruments are presented on Plate Nos. C-23, C-23A, C-25, C-25A, C-25 and C-28A.

These three piezometers monitor pressures in the downstream Dawson Formation and currently exhibit the highest piezometric levels of the downstream bedrock instruments, approximately elevation 5400 feet m.s.l. (piezometric level used in

[3] Meeting of Board of Consultants, Chatfield Dam, 16 Nov 1971

stability analysis). These instruments also exhibit minor fluctuations which are assumed to be related to the reservoir level.

A review of the data from Piezometer 504A reveals a slight decrease in level from approximately elevation 5408 feet m.s.l. in 1979 to the current level of approximately 5400 feet m.s.l. as shown on Plate Nos. C-23 and C-23A. There does appear to be a slight reflection of the reservoir elevation in the piezometer data, in particular in June 1995 during a high pool elevation. The tip elevation of Piezometer 504A; however, is 5338.3 feet m.s.l. This is approximately 18 feet above the elevation of the critical "failure plane" as documented on Plate No. B-6.

A review of the data from Piezometer 505B reveals a slight increase in level from approximately elevation 5396 feet m.s.l. in 1975 to the level of approximately 5400 feet m.s.l.in 1985 as shown on Plate Nos. C-25 and C-25A. From 1985 to the present the piezometric level has remained fairly constant at the approximate elevation 5400 feet m.s.l.. There does not appear to be a substantial reflection of the reservoir elevation in the piezometer data. The tip elevation of Piezometer 505B; however, is 5386.6 feet m.s.l. This is approximately 66 feet above the elevation of the critical "failure plane" as documented on Plate No. B-6.

A review of the data from Piezometer 561 reveals a definite decrease in level from approximately elevation 5415 feet m.s.l. in 1979 to the current level of approximately 5400 feet m.s.l. as shown on Plate Nos. C-28 and C-28A. There does appear to be a substantial reflection of the reservoir elevation in the piezometer data, primarily in 1995. The tip elevation of Piezometer 561 is 5297 feet m.s.l. The sensing zone is one foot below the tip to 3 feet above the tip. This is approximately the elevation of the assumed "failure plane" used in the stability analysis at Station 95+00.

The piezometric levels in these three instruments are currently at or below the piezometric level assumed in design (5400 feet m.s.l.); however, minor reflections of reservoir fluctuations have been observed primarily in Piezometer 561 in 1995. Additional bedrock piezometers with tip elevations in the "critical failure plane" would be warranted to better monitor the effects of higher pools. This would also enable the determination of the elevation and depth of the drain.

There are no piezometers located in the drain and very few in the downstream overburden. Additional piezometers in both the drain and downstream overburden would be warranted if a pool raise were to be implemented. Preliminary locations of proposed new piezometers are Stations 69+00, 81+00, 93+00 and 102+00. Additional piezometers would not only provide needed piezometric data during high pool elevations but would also enable the determination of the exact elevation and thickness of the drain.

The existing piezometer data is at or below that which was assumed in design (slope stability); however, two piezometers (504A & 561) in the Dawson Formation have exhibited a reflection to fluctuation in the reservoir elevation. Based on historic

records, primarily during the record pool in 1995 these piezometers reflected the pool change by 15 to 20%. Piezometer 504A is a pneumatic cell located at Station 68+90, Range 195 d/s. Piezometer 561 is an open tube device located at Station 92+90, Range 300 d/s. Both of these instruments monitor pressure in the Dawson Formation. A piezometric level of 5405 feet m.s.l. was assumed in the stability analysis at Station 68+50. Piezometer 504A is currently reading approximately 5401 feet m.s.l. If the normal pool elevation was increased by 12 feet, this instrument could, based on historic fluctuations, increase to the approximate elevation of 5403 feet m.s.l. This is still below what was assumed in the design. It is also stressed that the factor of safety in the original analysis at Station 68+50 was 1.62. Piezometer 561 located at Station 92+90 is currently reading the approximate elevation of 5398 feet m.s.l. A piezometric level of 5400 feet m.s.l. was assumed in the stability analysis at Station 95+00. The current piezometric level observed by Piezometer 561 is approximately 5398 feet. m.s.l. If the normal pool elevation was increased by 12 feet, this instrument could, based on historic fluctuations, increase to the approximate elevation of 5400 feet m.s.l., the elevation used in the design. A potential concern is for development of pressures that exceed those used in the design analysis at a reservoir elevation of 5500 feet m.s.l. The piezometric level in both Piezometer 504A and 561 would be expected to exceed the level used in design based on past performance. Piezometeric levels exhibited by these instruments do not pose a concern related to the Re-Allocation Project; however, this concern should be pursued as part of the routine dam safety program.

A review of the embankment movement data (inclinometers and survey points) does not reveal any areas of instability or potential instability. Movement data (surveys) along with inclinometer data is presented in Appendix D as discussed hereinafter. No relationship has been identified between movement (potential instability) and thrust of the pool; however, the maximum pool elevation to date has been approximately 5447.58 feet m.s.l. and this elevation was maintained for a relatively short time period.

8.0 Seepage Control.

8.1 Embankment Seepage.

8.1.1 General. The embankment was designed with a central symmetrical impervious core with 3V on 1H side slopes to provide an effective barrier against through seepage. A pervious inclined sand drain with a blanket outlet was placed adjacent to the downstream slope of the impervious core to intercept and dissipate any seepage through the embankment. According to the Embankment Performance and Criteria Report the thickness of the drain in the valley is 20 feet and transitions to a 10 foot thickness in the abutments.

8.1.2 Instrumentation Review. A review of the embankment (core) piezometer data, as presented in Appendix C, revealed a slight influence of the reservoir on piezometric levels for some of the instruments located in the impervious core, in particular the following instruments.

- **Piezometer No. 502A.** Piezometer 502A is a hydrostatic pressure cell located at Station 68+90. It is not know for sure if the cell is located in the bedrock, at the interface of the bedrock and the core or completely in the core. The observed piezometric level has fluctuated only slightly over the years, plotting at the approximate elevation of 5417. Since 1980 there has been; however, a very slight but steady overall decline in the piezometric level exhibited by this instrument.

- **Piezometer No. 502B.** Piezometer 502B is a hydrostatic pressure cell located in the core at Station 68+90. The observed piezometric level has fluctuated only slightly over the years, plotting at the approximate elevation of the downstream blanket drain; however, the piezometric level exhibited by this instrument increased approximately 4 feet in early 2005. The reason for this is unknown; however, this increase is not consistent with reservoir fluctuations. Pool influence is also not apparent in historical data. See Plate No.C-15, Appendix C for a detailed plot.

- **Piezometer No. 507C**. Piezometer 507C is a hydrostatic pressure cell located in the core at Station 81+20. The readings have been somewhat erratic; however, there is a general slight relationship with fluctuations in the pool elevation. See Plate No.C-16, Appendix C for a detailed plot.
- **Piezometer No. PZ95-03.** Piezometer No. PZ95-03 is an open tube located in the core at Station 81+20. The readings are approximately 10 feet below the reservoir elevation and 10 feet above the elevation of the downstream blanket drain. There is a definite relationship with fluctuations in the pool elevation. See Plate No.C-17, Appendix C for a detailed plot.

- **Piezometer No. 83+00/CTR**. Piezometer 83+00/CTR is an open tube device located in the core at Station 83+00. This instrument fluctuates only very slightly if at all with the elevation of the reservoir with the readings at or below the bottom of the blanket drain located downstream of the core. See Plate No.C-18, Appendix C for a detailed plot.

- **Piezometer No. 102+00/CTR.** Piezometer No. 102+00/CTR is an open tube device located in the core at Station 102+54. The readings fluctuate very slightly with a general decline over the past 10 years. The elevation of the readings is at or slightly above the top of the downstream blanket drain. No definite relationship with fluctuations in pool elevation is apparent. See Plate No. C-19, Appendix C for a detailed plot.

- **Piezometer No. 519C**. Piezometer No. 519C is a hydrostatic pressure cell located in the core at Station 102+54. Up to approximately 7 feet of fluctuation has been observed in this instrument since 1998. There has been a general increase (3'-5') over the past 7 years. The elevation of the readings is approximately 15' above the top of the downstream blanket drain. A slight

relationship with fluctuations in pool elevation is apparent; however, a current investigation has revealed that one of the lines is plugged making the data extremely questionable. See Plate No. C-20, Appendix C for a detailed plot.

Piezometer 512D (pneumatic cell) is the only core instrument with a piezometric level that approaches the level used in the stability analysis (5450 feet m.s.l.). This instrument has produced erratic data over the years. A recent investigation revealed that there is gas flow in one direction; however, there is no flow in the other direction. This makes the data questionable.

There are no piezometers located in either the upstream fill or downstream fill to evaluate; however, Piezometer 563 located adjacent to the fill in the abutment material (downstream) has been historically dry. Additional piezometers installed in the downstream fill are warranted if a pool raise were to be implemented.

8.2 Foundation Seepage.

8.2.1 General. The overburden materials, in the valley and abutments, are of such high permeability as to require a positive form of underseepage control so that excessive losses of stored water and/or seepage concerns do not occur. The final adopted and approved form of underseepage was a backfilled trench located at the centerline of the embankment alignment. Numerous piezometers/pressure cells are located in the upstream overburden. These instruments reflect a direct influence of the reservoir which would be as expected. All piezometric levels are within normal trend and range.

Studies of types and associated costs of underseepage controls were reported in Design Memorandum No. PC-9, Initial Earthwork -Valley Cutoff. The final adopted and approved form of underseepage control was a backfilled impervious trench located at the centerline of the embankment alignment. The limits of the cutoff trench are from station 40+00 in the right abutment to its interception with the spillway structure in the left abutment at approximate station 123+00. The bottom width of the trench was designed to be a minimum of 35 feet in the valley and 25 feet in the abutments.

The cutoff trench was intended to extend a minimum of 3 feet into the Dawson bedrock formation. After the cutoff trench was excavated to the required depth, auger holes were then drilled at a minimum of 100 feet on centers to a depth of 30 feet to explore possible continuous layers of sandstone beneath the trench. Where layers were found, they were then excavated and replaced with compacted impervious material. The approximate maximum depth considered practical to excavate was 10 feet. Due to the deeper excavations below the regular bottom of the trench, it was necessary to reduce the width of the trench to a width slightly less than the original planned width; however, in no instance was the width allowed to be less than 25 feet. During drilling when sand layers were encountered, laboratory testing was used to assist in the decision to remove or leave the sand layer. If the

sand had less than 20 percent passing the number 200 sieve size and a plasticity index of less than 5, it was removed and replaced with impervious material.

Pump tests were performed on selected piezometers to further investigate the permeability and susceptibility of the Dawson Formation to seepage. Bailing and recharge measurements were made on five (5) piezometers which had been installed in the Dawson Formation. Permeabilities at each piezometer were computed from the recharge tests by the Jacobs Modification to the Theis Recovery Method of Analysis. The thickness of the aquifer was taken as the depth of water in each piezometer which in most cases was 50 feet. The derived permeabilities were considered as semi-impervious or very low. From these tests and the pressure tests, it was concluded that the Dawson Formation had a relatively low permeability and would be relatively free of under-seepage problems.

Investigations were made to determine whether seepage could be a problem either under or around the cutoff trench. It was found that any seepage that might occur under the cutoff in the sandstones or around the end of the cutoff in the right abutment would be of such a small quantity that it would not be particularly noticeable. As an added precaution to intercept seepage and/or prevent piping of impervious material, a pervious section was placed on the downstream side of the cutoff trench which was then tied to the blanket drain.

8.2.2. Instrumentation Review. A review of the bedrock piezometer data, as presented in Appendix C, revealed considerable headloss across the cutoff trench. Bedrock piezometers located at or upstream of the cut-off trench are responsive to pool fluctuations with minimal headloss while those downstream do not exhibit a definite relationship with the reservoir and are in many cases exhibiting a downward trend, with up to 60 feet of headloss (Piezometer No. 560 @ Station 68+90). All of the downstream bedrock piezometers exhibit water/pressure levels within or below the elevation of the downstream blanket drain. All piezometric levels are within (historic) normal trend and range. The following bedrock piezometers are discussed in more detail.

Cross sections of Chatfield Dam exhibiting bedrock piezometric gradients are presented on Plate Nos. C-11 thru C-14 in Appendix C.

- **Piezometer No. 536.** Piezometer No, 536 is a hydrostatic pressure cell located approximately 200 feet upstream at Station 68+85. The instrument appears to be slightly responsive to pool fluctuations; however, there has been an overall downward tend over the past 10 years indicating possible siltation upstream and/or decreased permeability of the bedrock. See Plate No. C-21, Appendix C for a detailed plot.

- **Piezometer No. 41.** Piezometer No. 41 is an open tube located approximately 25 feet upstream from the dam centerline at Station 68+90. The tip is located in the bedrock slightly upstream of the cutoff trench. This instrument is highly

responsive to pool fluctuations with only 1-2 feet of headloss. See Plate No. C-22, Appendix C for a detailed plot.

- **Piezometer No. 504A.** Piezometer No. 504A is a hydrostatic pressure cell located approximately 195 feet downstream at Station 68+90. There has been an overall downward tend over the past 10 years indicating possible siltation upstream and/or decreased permeability of the bedrock. The headloss between Piezometer No. 536 located in the foundation upstream of the cut off and Piezometer No. 504A located in the foundation downstream of the cut off is approximately 10 feet. An apparent or definitive relationship with pool fluctuations has been identified as discussed in Paragraph 7.5. See Plate No. C-23 & C-23A, Appendix C for detailed plots.

- **Piezometer 505A.** Piezometer No. 505A is a hydrostatic pressure cell located approximately 400 feet downstream at Station 68+90. This instrument appears to be slightly responsive (less than 504A). There has been no trend over the past 10 years. The headloss between Piezometer No. 536 and Piezometer 505A is approximately 15 feet. No apparent or definitive relationship with pool fluctuations has been identified. See Plate No. C-24, Appendix C for a detailed plot.

- **Piezometer 505B.** Piezometer No. 505B is a hydrostatic pressure cell located approximately 400 feet downstream at Station 68+90. This instrument appears to be slightly responsive (less than 504A). The headloss between Piezometer No. 536 and Piezometer No. 505B is approximately 10 feet. No apparent or definitive relationship with pool fluctuations has been identified except for as discussed in Paragraph 7.5. See Plate No. C-25 & C-25A, Appendix C for detailed plots.

- **Piezometer 560.** This instrument is located approximately 950 feet downstream in the Dawson Formation at Station 68+90. There is approximately 60 feet of headloss as compared to the pool elevation. There has been a very slight overall downward trend over the past 10 years indicating possible siltation upstream and/or decreased permeability of the bedrock. No apparent or definitive relationship with pool fluctuations has been identified. See Plate No. C-26, Appendix C for a detailed plot.

- **Piezometer 79+00.** This instrument is an open tube device located approximately 25 feet upstream from the dam centerline at Station 79+00. The tip is located in the bedrock slightly upstream of the cutoff trench. This instrument is highly responsive to pool fluctuations with only 1-2 feet of headloss. See Plate No. C-27 for a detailed plot.

- **Piezometer 551D & 551S.** These instruments are closed tube piezometer systems equipped with a pressure gages. They are located 750 feet downstream at Station 87+50. Prior to 2005, Piezometer 551D was experiencing a definite rise in piezometric level. In May of 2005 both gages were replaced. Since that

time Piezometer 551D has read approximately elevation 5400 feet m.s.l., while 551S has read approximately 5390 feet m.s.l.

- **Piezometer No. 561.** Piezometer No. 561 is an open tube device located approximately 300 feet downstream in the bedrock at Station 93+00. The instrument appears to be responsive. There has been an overall downward tend (approximately 5 feet) over the past 10 years indicating possible siltation upstream and/or decreased permeability of the bedrock. An apparent or definitive relationship with pool fluctuations has been identified as discussed in Paragraph 7.5.See Plate No. C-28 & C-28A, Appendix C for detailed plots.

- **Piezometer 102+00/25US.** This instrument is located in the bedrock, 25 feet upstream at Station 102+54. The tip is located slightly upstream of the cutoff trench. The tip is located in the bedrock slightly upstream of the cutoff trench. This instrument is highly responsive to pool fluctuations with approximately 6 feet of headloss. See Plate No. C-29, Appendix C for a detailed plot.

- **Piezometer 486.** This instrument is an open tube piezometer located approximately 25 feet upstream from the dam centerline at Station 102+54. The tip is located in the bedrock slightly upstream of the cutoff trench. This instrument is highly responsive to pool fluctuations with approximately 4 feet of headloss. See Plate No. C-30, Appendix C for a detailed plot.

- **Piezometer 520A.** This instrument is a hydrostatic pressure cell located approximately 125 feet downstream in the Dawson Formation at Station 102+54. The instrument appears to be responsive but with no definite relationship with pool fluctuations. There has been an overall downward tend (approximately 3 feet) over the past 10 years indicating possible siltation upstream, decreased permeability of the bedrock and/or dissipation of pore pressure. The average headloss is approximately 45 feet as compared to the reservoir. No apparent or definitive relationship with pool fluctuations has been identified. See Plate No. C-31, Appendix C for a detailed plot.

Based on a review of the foundation piezometeric data, seepage within the Dawson Formation would not pose a concern under the proposed reallocation.

8.3 Overburden. The downstream overburden piezometeric data, as presented in Appendix C, revealed considerable headloss. All piezometric levels are all within historic (normal) trend and range. There has been a general slight decreasing trend observed in many of the instruments. All of the downstream overburden piezometers exhibit water/pressure level within or below the elevation of the blanket drain.

A “wet area” has been identified just upstream of the outlet works stilling basin area at various times since construction of the dam. Normally the area is dry but on rare occasions water is observed emerging the slope. Historic information points towards

precipitation as the source of the wet area. Additional piezometers would be beneficial in determining the exact source(s) of the water in this area.

The following downstream overburden piezometers are discussed in more detail.

- **Piezometer 522.** This instrument is located in the overburden approximately 550 feet downstream at Station 102+54. There is no definitive relation with pool fluctuations. The average headloss is approximately 50 feet as compared to the reservoir. See Plate No. C-32, Appendix C for a detailed plot.

- **Piezometer 558.** This instrument is located in the overburden approximately 725 feet downstream at Station 102+54, which is downstream of the toe drain. There is no definitive relationship with pool fluctuations. The average headloss is approximately 45 feet as compared to the reservoir. See Plate No. C-33, Appendix C for a detailed plot.

- **Piezometer 555.** This instrument is located in the overburden approximately 625 feet downstream at Station 85+50, which is downstream of the toe drain. There is no definitive relationship with pool fluctuations. There is; however, a very slight downward trend in the piezometric level. The average headloss is approximately 60 feet as compared to the reservoir. See Plate No. C-34, Appendix C for a detailed plot.

- **Piezometer 562.** Piezometer 562 is located 443 feet downstream at Station 102+92. This instrument was abandoned in 1980.

- **Piezometer 563.** Piezometer 563 is located approximately 350 feet downstream at Station 90+00. This instrument has been historically dry. See Plate No.C-35, Appendix C, for a detailed plot.

A review of the toe drain data revealed that the drain has always been dry indicating evidence of a positive cutoff; however, higher reservoir elevations have not been experienced to assess the overall effectiveness of the cutoff.

Based on a review of the overburden piezometeric data, seepage within the overburden would not pose a concern under the proposed reallocation.

9.0 Movement Review

9.1 General. A settlement analysis was performed (during design) on the embankment impervious core and impervious cutoff trench at station 95+00 where the maximum height of impervious core and cutoff trench was attained. Since the surface foundation clays beneath the embankment were removed, it was determined that settlement of the pervious foundation would take place during construction and that the critical materials for determining residual settlement or settlement after completion of construction would be the embankment core and cutoff trench materials.

Consolidation tests of the impervious cutoff trench material were used in the settlement analyses. The total height of material analyzed was 187 feet. The total settlement was computed to be 5.6 feet of which 3.2 feet (56%) would occur during construction and 2.4 feet (44%) would occur after completion of the embankment. Only 9 inches of overbuild were actually provided for residual settlement of the embankment. This was an arbitrary decision which recognized that a gravel road on top of the dam would provide additional buildup of the crest and that there usually is some conservancy in the computations and procedures of analyses, due to inaccuracies of testing and differences in rate of load application to that assumed.

9.2 Instrumentation Analysis. Typical movement data (survey) is presented in Appendix D for information. Plate Nos. D-1 through D-4 presents vertical movement of crest, slope and toe movement markers. Vertical movement plots of the crest movement markers indicate a maximum consolidation of the embankment and cutoff trench of approximately 0.75 feet (Point C-15) from November 1975 to 2007.

Horizontal movement data for the crest, slope and toe markers is presented on Plate Nos. D-5 through D-9. Up to approximately 0.2 feet of horizontal movement has been observed with the exception of Points S-1 and S-2 as of the 2007 survey. Point S-1 has experienced approximately 0.30 feet of movement in the south direction while Point S-2 has experienced approximately 0.7 feet of horizontal movement also in the south direction. These points are located on the downstream (north) side of the overbuild section. Movement of these points to the south would not be consistent with their locations. Point S-1 has exhibited erratic data from the early 1980's. Possibly these points have been disturbed/damaged.

Foundation settlement data at Stations 70+00 and 90+00 is presented on Plate Nos. D-10 and D-11. Foundation settlement from 1971 to 2007 was measured at approximately 2.5 feet with the majority (1.5 feet) occurring between 1971 and 1975. Currently, the crest markers are exhibiting a movement rate of approximately 0.01 feet per year while the settlement gage movement was essentially zero from 2001 to 2003. Settlement since 1980 has been approximately 0.5 feet or 0.02 feet per year. Current (2007) top of dam centerline surveys indicates a minimum elevation of 5526.729 at Station 65+00 as shown on Plate No. D-12. The design top of dam elevation is elevation 5527 feet m.s.l. This results in a low area approximately 3.25" below the design elevation.

Survey movement data of the outlet works including the intake structure bridge is presented on Plate Nos. D-13 through D-16. As can be observed, no excessive or out of trend data has been identified.

There are 12 slope inclinometers (tiltmeters) located at Chatfield Dam as shown on Plate No. D-17. An inclinometer is a metal tube approximately 3 inches in diameter that is placed in a drill hole through the embankment/abutment/foundation. The purpose of this instrument is to measure active subsurface horizontal movement at

various depths and identify areas of active instability or potential instability. Inclinometer data is presented for information in Appendix D, Plate Nos. D-18 thru D-31. A review of the inclinometer data indicates no active movement zones and no apparent movement related to pool thrust. Inclinometer 496 located at Station 104+54, Range167 D/S (Plate D-23) indicates what could be perceived as "movement zone" in the east direction. A review of the cumulative deviation plot (shape of pipe) on Plate D-23A revealed a sharp bend at this location resulting in poor quality data. This bend probably occurred during installation and/or settlement of the pipe. Inclinometer 545 located at Station 81+10, Range 17 D/S (Plate D-29) displays somewhat erratic data. The data does not appear to be related to movement of the embankment/foundation. The cumulative deviation (shape of pipe) plot for Inclinometer 545, presented on Plate No. D-30, indicates considerable deviation (approximately 6.5 feet) of the pipe from vertical. This normally affects the quality of the readings because just a slight change in depth produces a big change in the slope of the pipe. The checksums presented on Plate D-31 indicates relatively poor data below the depth of approximately 140 feet. This corresponds to the substantial change in the deviation of the pipe as shown on Plate D-30.

Based on a review of survey and inclinometer data, movement (settlement/instability) would not pose a concern under the proposed re-allocation.

10.0 Structural Evaluation.

10.1 General. The purpose of the structural evaluation was to determine if it is feasible to raise the normal and maximum pool elevations at Chatfield Dam without requiring modification to the existing outlet works structure and/or spillway structure. Pool elevations used in the original design calculations were compared with the proposed new pool elevations and the outlet works structure was evaluated to project how these new pool elevations may affect the existing structures. A brief description of the structures located at Chatfield Dam is presented in Paragraph 3.0.

10.2 Critical Structures. Critical structures are defined as those who's failure during or immediately after an earthquake could result in loss of life. The ability to lower the reservoir pool following an earthquake may be required to relieve pressure head on a damaged embankment or to inspect and repair the embankment in order to prevent loss of pool.

The existing guidance available on whether the intake structure should be classified as critical or not states that the intake structure is considered critical if any of the following four scenarios is likely to occur. (I) The intake structure can no longer discharge water and the embankment is damaged, but not breached right away leading to long-term use of the spillway. This could cause severe erosion and failure of the spillway, the abutment, or the embankment dam. (II) The embankment does not fail right away but is damaged such that the hydraulic capacity of the spillway is reduced because of the need to restrict the pool level to prevent overtopping. In this scenario, the outlet works must be used to prevent overtopping the dam for the design

flood event. (III) The outlet works must be used to draw down the pool to a level below the spillway crest to prevent piping/internal erosion in the embankment. This assumes that the intake structure is capable of draw down rates in the range of 3 to 5 feet per day. (IV) Failure of the intake structure could cause the outlet conduit to rupture leading to piping and eventual failure of the embankment. Determination of a critical/non-critical rating will be pursued as part of the Seismic Phase I Study.

10.3 Study Data.

10.3.1 Intake Structure. The intake structure is the primary outlet structure at Chatfield Dam. In the event of a large flood event, it is imperative that the intake structure sustains functionality; however, this may not be the case depending on the results of the Phase I Seismic Evaluation. In the original design, the stability of the intake structure was designed for 4 different cases as shown below:

Case I. Construction Condition.

Reservoir Empty
Dead Load of Structure (Including Bridge Reaction)
Earth Loads
Wind Load (In Direction to produce most severe foundation pressures)

Case II. Normal Operating Condition.

Reservoir at elevation 5426 (Conservation Pool)
All Gates Open
Dead Load of Structure
Earth Loads
Wind Loads
Full Uplift on Base

Case III. Full Flood Condition.

Reservoir at Elevation 5500 (Crest of Ungated Spillway)
Emergency Gates Closed
Dead Load of Structure
Earth Loads
Wind Load
Full Uplift on Base

Case IV. Maximum Flood Condition.

Reservoir at Elevation 5521.6 (Max Reservoir Elevation)
Emergency Gates Closed
Dead Load of Structure
Earth Loads

Wind Load
Full Uplift on base

Note: In addition to these load conditions. Case IA, IIA, and IIIA, as presented on Plate E-1, were analyzed in the same way, except with an earthquake load of 0.10g substituted for the wind load.

The original stability calculations for Cases I through IV as well as IA through IIIA can be seen on attached Plate No. E-1 located in Appendix E. For the purposes of this study, Case I, the construction condition, does not apply and does not need to be looked at for the new pool volumes. Also, Case III, the Full Flood Condition, remains the same as it was in the original design of the intake structure. Case I originally yielded a shear-friction sliding safety factor of 7.56 (or 6.36 for earthquake), and Case III yielded a safety factor of 13.06 (or 6.33 for Seismic). Both cases yielded high safety factors which provide assurance that the structure would perform well in a large flood event.

Cases II and IV are the most important calculations to investigate to check if raising the normal pool elevation at Chatfield Dam is a feasible option. Case II designates a reservoir pool elevation at 5426.0 feet m.s.l. In the original design, Case II calculations yielded a shear-friction sliding safety factor of 13.64 under normal operating conditions and a safety factor of 7.73 when seismic loading was considered. The structural stability of the intake structure is marginally more stable under the Case II loading conditions with the new pool elevation of 5444.0 feet m.s.l. The increased stability of the intake structure can be attributed to the increase in vertical water loads on the intake structure when raising the pool versus slightly increased horizontal loads improving the stability of the structure. This case will be looked at as a part of the Phase I Seismic Evaluation.

Case IV specifies the reservoir elevation at max elevation of 5521.6 ft. In the original design calculations, Case IV yielded a sliding stability safety factor of 13.0. Case IV causes no major concerns for the Re-Allocation; however Case IV will be reviewed in the seismic review since seismic forces were not originally considered in this case.

Due to the possibility of high hydrostatic head, the intake structure was originally designed with walls and components with adequate internal strength to satisfy the allowable shear and moment requirements. All structures were designed with enough steel reinforcement to meet minimum temperature and shrinkage requirements. Also, the working stresses for Cases I and IV and all cases with earthquake loads were increased by 1/3rd for conservatism. In the most recent Periodic Inspection Report (2008), it was noted that the intake structure's concrete surfaces were in excellent condition with only minor shrinkage and map cracking which ensures that the structure should function as designed.

The bulkheads, gates, and valves in the intake structure were all originally designed to handle max flood conditions as well as the max pool of 5521.6 feet MSL. In fact,

the design of the intake structure was based on the loading cases used for stability or a combination of loadings which produced the most severe stresses. These structures are expected to perform just as well as they currently do in a max pool event.

The oblong conduit was originally chosen over circular conduits because it was much more economical to build and was comparable to the circular conduit in strength. This conduit also was designed for the most severe loading conditions and will not be affected by the change in pool elevations entailed in this study.

The stilling basin was originally designed for a worst case scenario flood discharge condition of 8150 c.f.s. which is equivalent to the max discharge possible to pass through the outlet works. This structure also should not be of any concern with the newly proposed pool elevations.

The intake structure service bridge was designed for the maximum pool loading condition. In addition to these loading conditions the structure was designed to bear the AASHTO H-20 live load or a 25-ton mobile truck crane (37.5 tons total load), plus a low boy parked simultaneously on the same span as the crane. The service bridge is not a concern under the original loading criteria with a new normal pool elevation of 5444 Ft. MSL.

10.3.2 Spillway Structure. The spillway structure at Chatfield Dam was originally designed for similar loading conditions as the outlet works structures. The original maximum flood that the spillway was designed for is the only condition that would change due to raising the pool elevation according to this study. However, similar to the outlet works structures, there are no major concerns regarding the structural integrity of the spillway structures.

11.0 Conclusions. No immediate dam safety concerns have been identified based on either the existing normal reservoir elevation of 5432 feet m.s.l. or on a projected reservoir elevation of 5444 feet m.s.l considering static loading.

No indications of instability have been identified either by field inspections or by the instrumentation program after approximately 35 years of service.

Based on fluctuation of piezometer data as discussed hereinbefore, there is the potential concern for development of excess pressures in the foundation (Dawson Formation) at the reservoir elevation of 5500 feet m.s.l (spillway crest pool). Based on piezometer projections, the piezometric levels in both Piezometer 504A and 561 may exceed the levels used in the original slope stability analyses for pool elevation 5500 feet m.s.l. This does not pose a concern for the re-allocation project since the spillway pool elevation does not change as a result of the re-allocation project. This concern should be evaluated as a part of the routine dam safety program.

Due to the relatively responsive nature of some of the piezometers located in the core of the embankment, close monitoring of these instruments would be warranted during a reservoir level approaching the spillway crest (El. 5500 Ft.). This does not pose a concern for the re-allocation project since the spillway pool elevation does not change as a result of the re-allocation project. This concern should be evaluated as a part of the routine dam safety program.

No evidence of seepage concerns have been identified since construction of the project (35 years). All piezometric levels are considered to be within normal trend and range. The downstream toe drain has always remained dry. Minimal fluctuation except for a general overall decline in pressure has been observed in the bedrock piezometers located near the downstream toe (Piezometers 560, 557, 564, and 522). The most responsive downstream bedrock instrument is Piezometer 561. Piezometer 561 is an open tube devices located at Station 93+00, approximately 300 feet downstream. The piezometric level exhibited by this device initially reflected pore pressure during construction and then was affected by the reservoir impoundment. The piezometric level in this instrument has decreased approximately 15 feet since impoundment of the reservoir; however, small spikes in the piezometric level can be seen during periods of increased reservoir level (1979). This instrument has fluctuated approximately 2 feet over the past 10 years during “normal” fluctuations of the reservoir (approximately 10 feet). Currently the piezometric level in this instrument is at the approximate elevation of the bottom of the blanket drain.

All of the structures at the site have been designed to withstand the small increase in loading caused by the proposed pool elevations. In addition to this, the most recent periodic inspection report (2008) found these structures to be in very good condition which provides confidence that these structures are still in a condition to function as designed. A review of the instrumentation data (piezometers, inclinometers and survey points) did not reveal a relationship between movement (potential instability) and thrust of the pool; however, the maximum pool elevation to date has been approximately 5447.58 and this was for a relatively short time period.

The primary concern for the structures at Chatfield Dam stems from the most recent Seismic Safety Review which recommended a Phase I study.

Although continued monitoring will be required, raising the normal pool elevation by up to 12 feet should not have a direct bearing on the adequacy of the slope protection material; however, the slope protection material will continue to be monitored during routine dam safety inspections (monthly, annual, periodic,…). In addition to this, effort will be made to inspect existing areas of riprap displacement during low reservoir elevations.

Based on a review of design assumptions, instrumentation data and performance since completion of Chatfield Dam, it is concluded that the new “normal” pool elevation (El. 5444) proposed in this reallocation study will not adversely impact the integrity of the embankment or structures. It is emphasized that this conclusion is based strictly on

static loading scenarios. Although no dam safety concerns have been identified for the proposed reservoir loading, based on project performance and the instrumentation program, increased monitoring of the project would be pursued as part of the routine dam safety program to assure continued safe operation of the dam. This would include the development and implementation of a Reservoir Raise Monitoring Plan which would include additional inspection efforts, instrumentation data acquisition and data analysis. The Project Surveillance Plan and Emergency Action Plan should also be updated as appropriate.

Installation of additional instrumentation prior to the pool raise along with an increase in instrumentation readings and inspection frequencies during and following the pool raise would be warranted.

12.0 Recommendations. Specific recommendations are as follows:

- Add new piezometers in the overburden near the outlet works at Station 105+00.
- Add new piezometers in the downstream drain at Stations 69+00, 81+00, 93+00 and 102+00 to establish elevation and depth of the drain and to monitor effectiveness of the drain.
- Add new piezometers in the downstream fill at Stations 69+00, 81+00, 93+00 and 102+00 to monitor an historic “wet area”.
- Add new piezometers in the downstream Dawson Formation at Stations 69+00, 81+00, 93+00 and 102+00 to monitor potential excessive pressures.
- Develop a reservoir raise monitoring plan addressing frequencies of inspection, instrumentation data acquisition including the toe drain and data analysis.
- Revise the Emergency Action Plan and Surveillance Plan as appropriate.
- Maintain routine (monthly, Annual, Periodic) inspection of the upstream slope protection. Effort should be made to inspect existing areas of riprap displacement during low reservoir elevations.

REFERENCES

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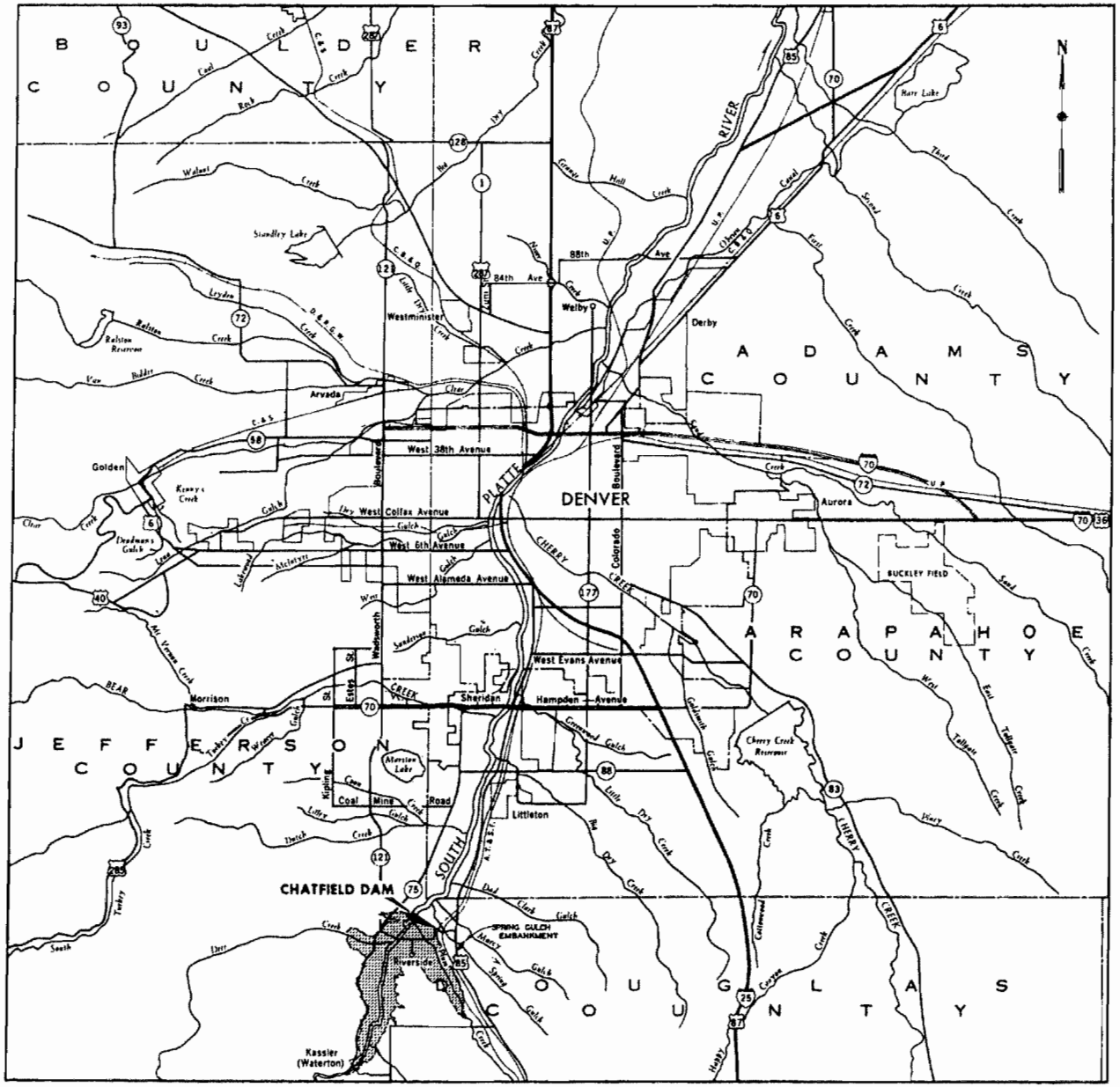
Meeting of Board of Consultants, Chatfield Dam, 16 Nov 1971

ACRONYMS

approx.:	approximate
cfs:	cubic feet per second
Cfs:	Cubic feet per second
COE:	Corps of Engineers
D/S:	Downstream
Elev. (el):	Elevation
ER:	Engineering Regulation
Ft, FT, ft:	feet
H	Horizontal
in.:	inch
lb/cft:	pounds per cubic foot
max.:	maximum
min.:	minimum
msl	mean sea level
N:	North
Nos.:	Numbers
P:	Piezometer
psf:	pounds per square foot
psi:	pounds per square inch
Pz:	Piezometer
rt	right
SC:	Slope and Crest Movement Marker
SG:	Settlement Gage
sq in.:	square inch
Sta.:	station
T:	Inclinometer designation
U/S:	Upstream
USACE:	United States Army Corps of Engineers
V:	Vertical
W:	West
wt:	weight
yrs:	years



VICINITY MAP

SCALE IN FEET

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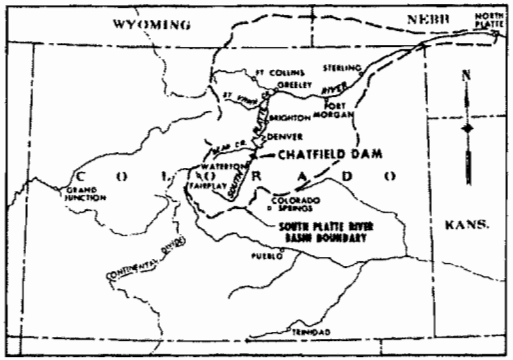


LOCATION MAP

NO SCALE

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

SOUTH PLATTE RIVER, COLORADO

CHATFIELD DAM AND RESERVOIR

EARTHWORK - STAGE III

VICINITY AND LOCATION MAPS

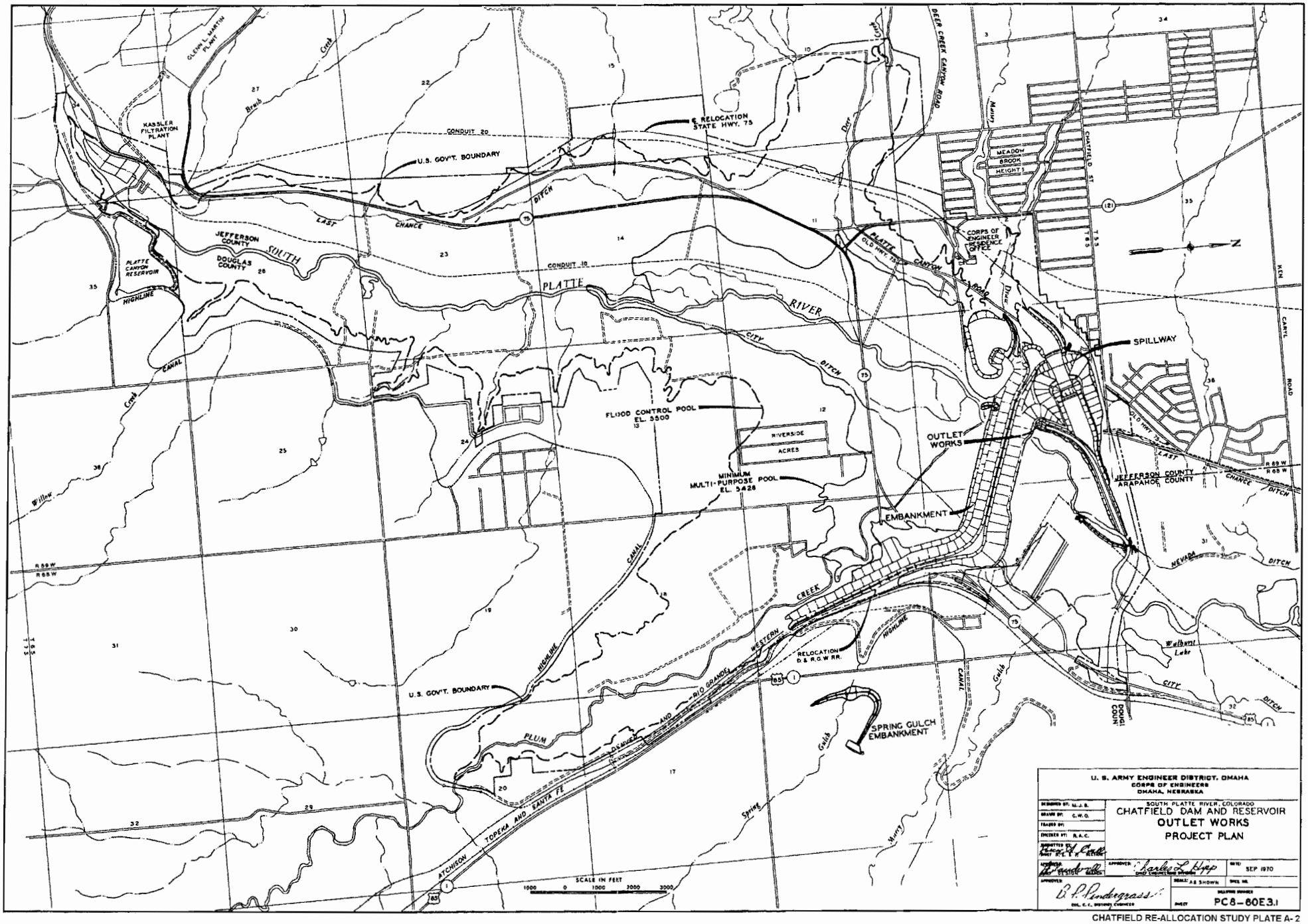
DESIGNED BY: R. J. M.
DRAWN BY:
TRACED BY:
CHECKED BY: C. V. J.

DATE: JAN. 1970

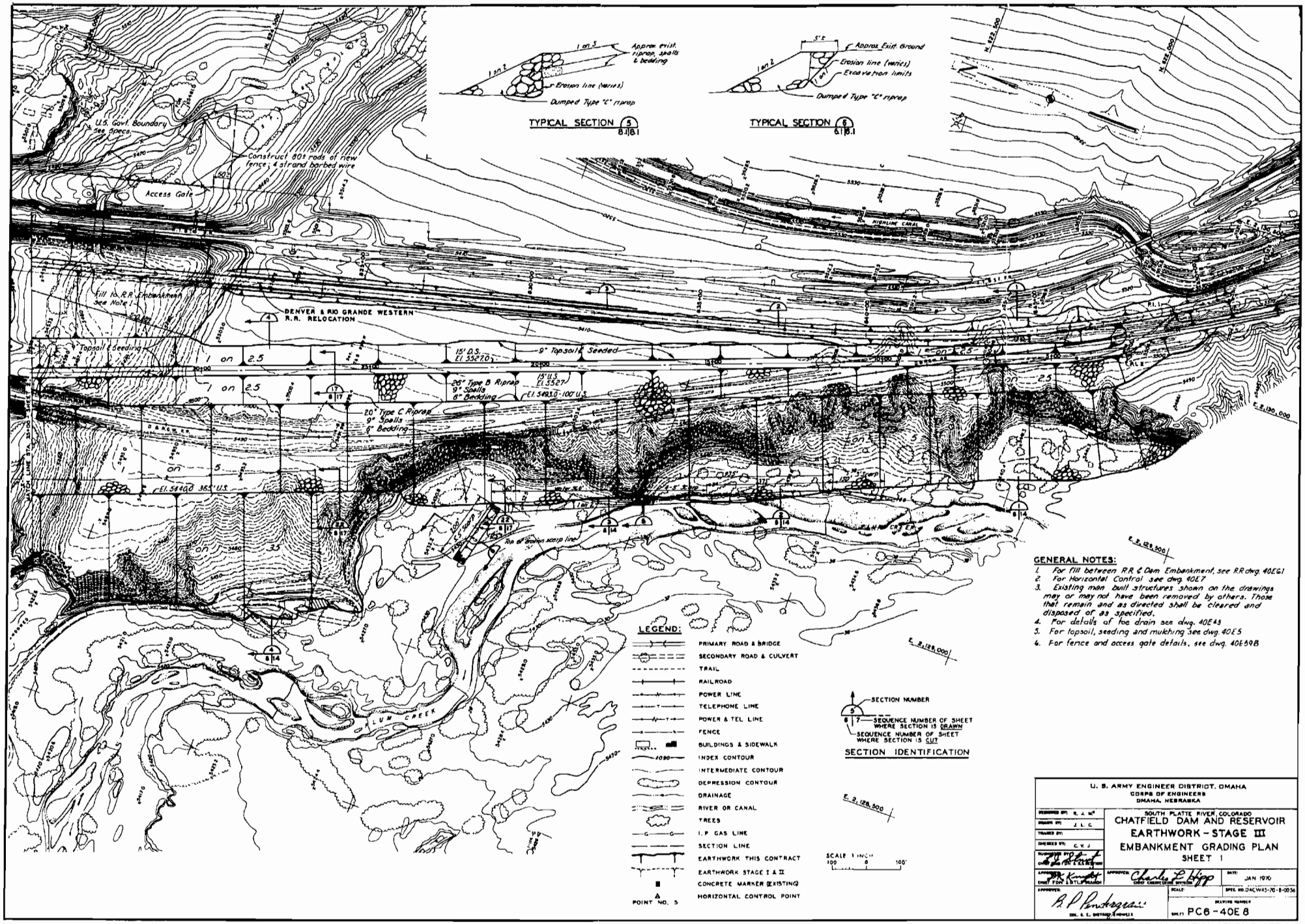
SCALE: AS SHOWN

SHEET PC6 - 40E1

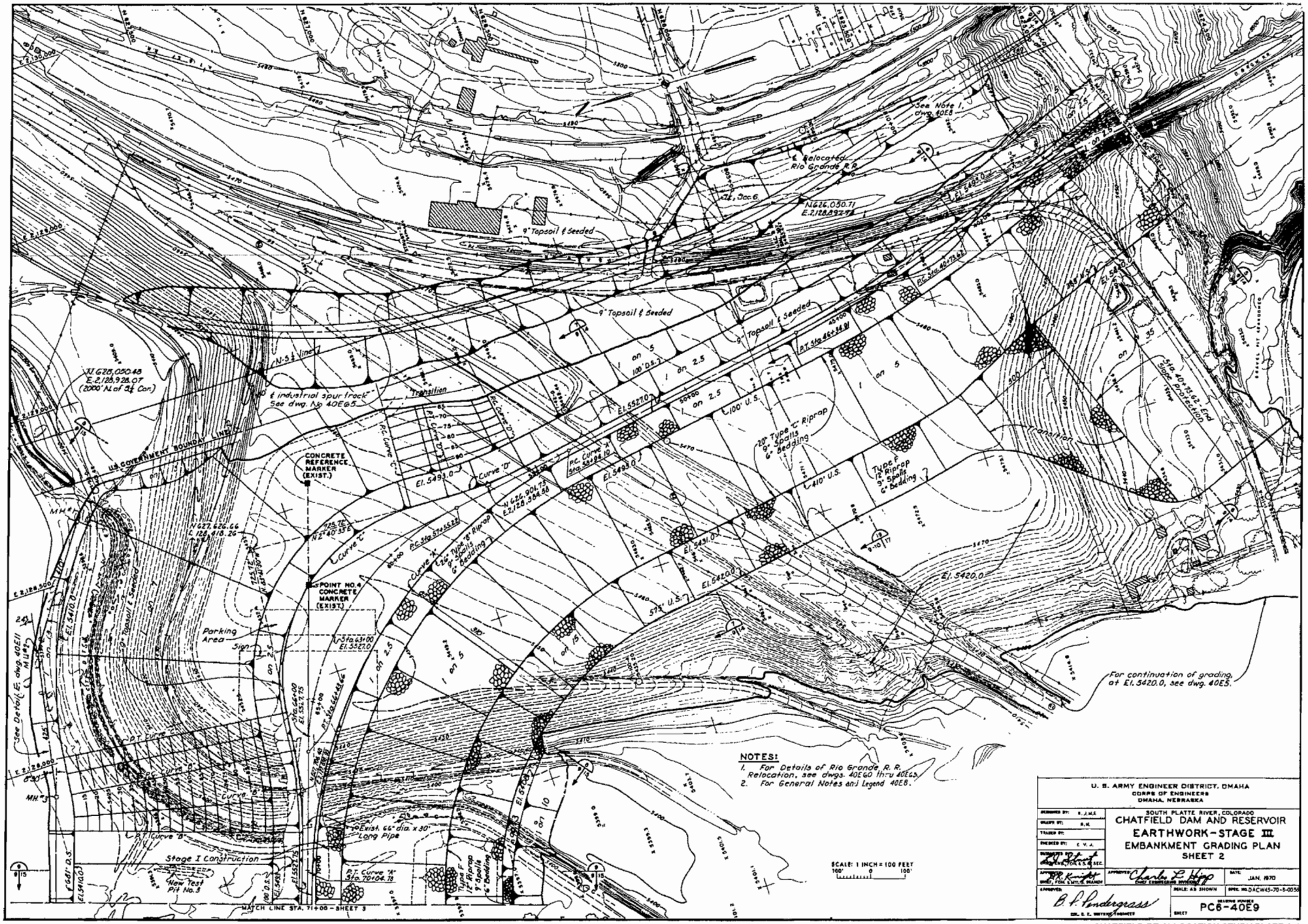
CHATFIELD RE-ALLOCATION STUDY PLATE A-1



CHATFIELD RE-ALLOCATION STUDY PLATE A-2



CHATFIELD RE-ALLOCATION STUDY PLATE A-3



NOTES:

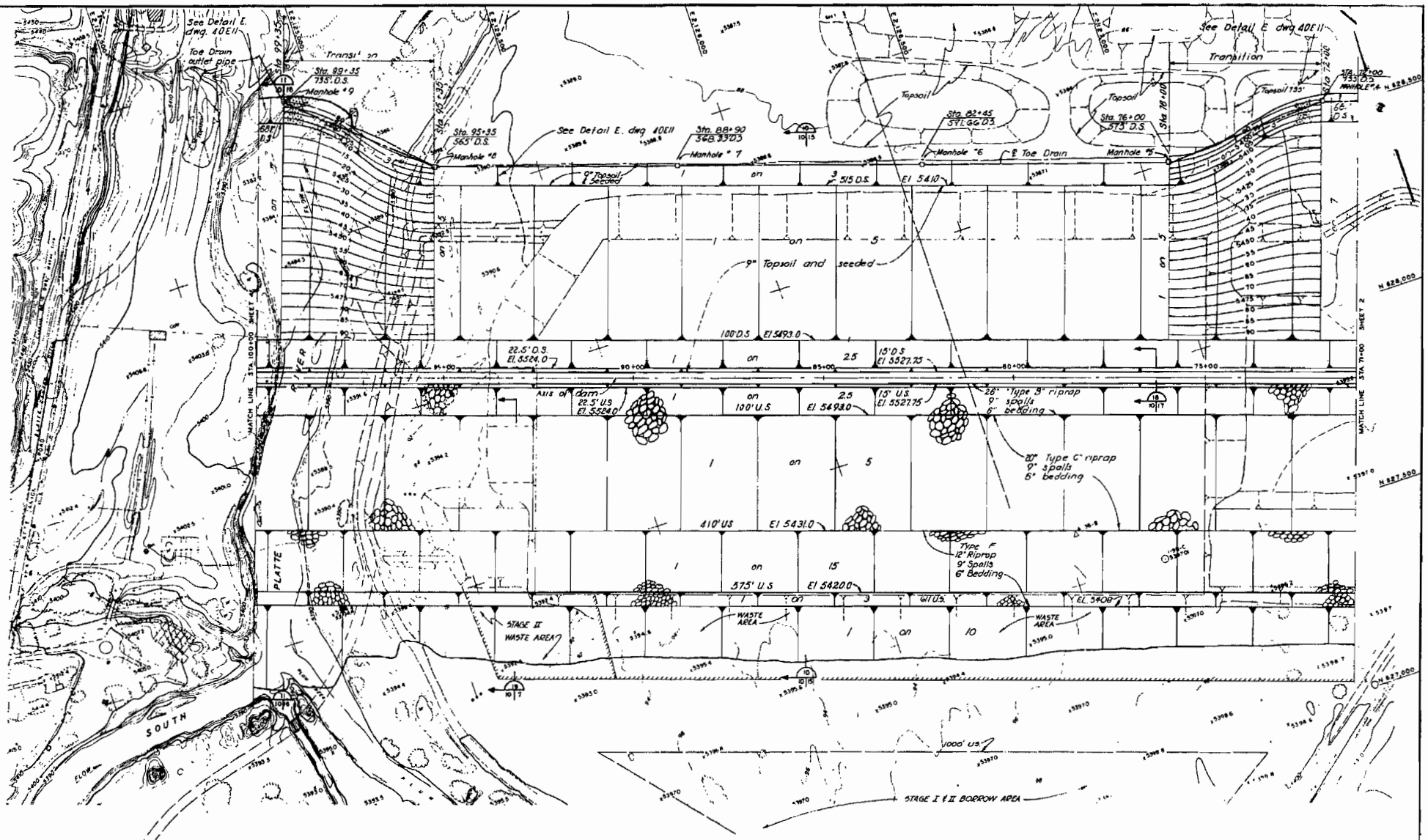
1. For Details of Rio Grande R. R. Relocation, see dwgs. 40E60 thru 40E63.
2. For General Notes and Legend 40E8.

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EARTHWORK - STAGE III
EMBANKMENT GRADING PLAN
SHEET 2

DESIGNED BY: R. J. M. E.
DRAWN BY: R. M.
TRACED BY:
CHECKED BY: E. V. J.
SUBMITTED BY: R. J. Knight, CHIEF, STRUCTURES SEC.
APPROVED: R. P. Knight, CHIEF, FOUN. & MTLS. BRANCH
APPROVED: Charles L. Hipp, CHIEF, ENGINEERING DIVISION
DATE: JAN. 1970
APPROVED: B. P. Pendergrass, COL. C. E. DISTRICT ENGINEER
SCALE: AS SHOWN
SPEC. NO. DACW45-70-B-0056
SEQUENCE NUMBER SHEET: PC6-40E9

CHATFIELD RE-ALLOCATION STUDY PLATE A-4



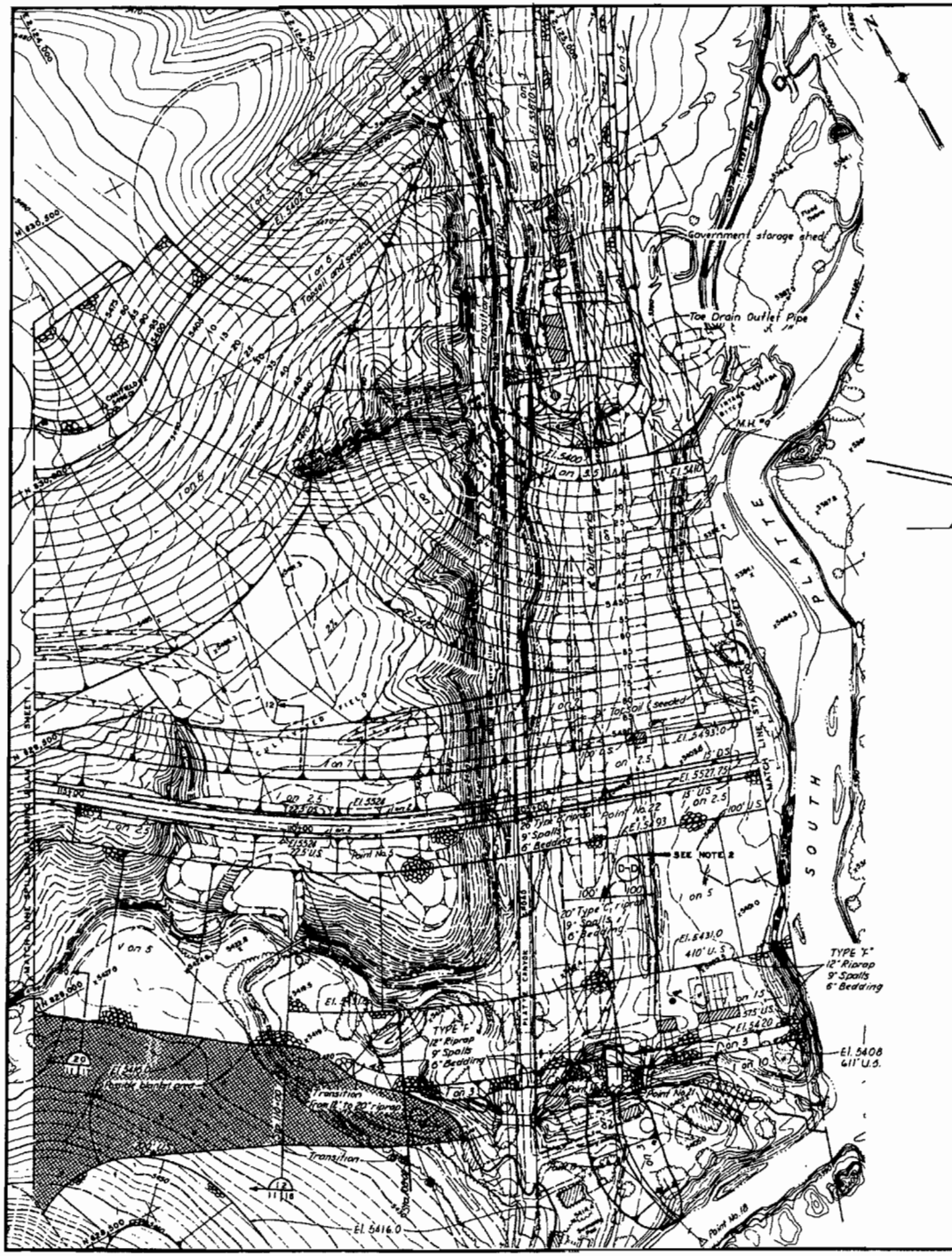
NOTE:
1 For General Notes and Legend, see dwg. 40E8.

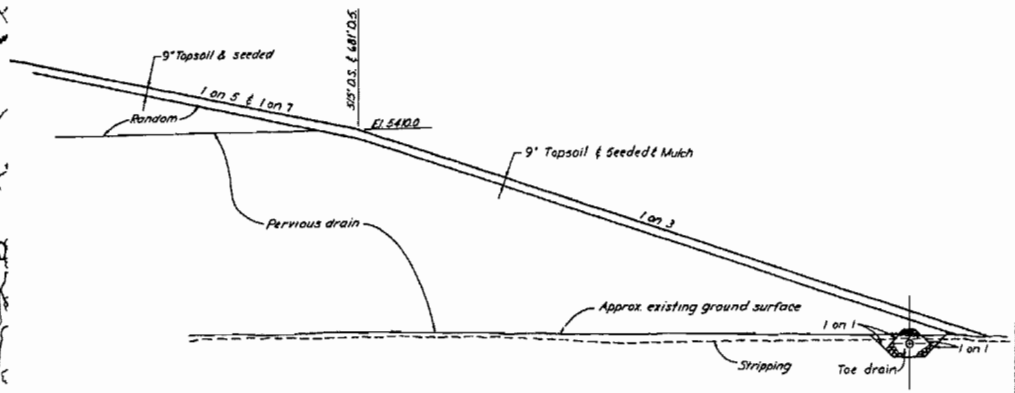
SCALE 1 INCH = 100 FEET
100 0 100

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EARTHWORK - STAGE III
EMBANKMENT GRADING PLAN
SHEET 3

DESIGNED BY R. J. M. S.
DRAWN BY R. L. M.
TRACED BY
CHECKED BY C. V. J.
SUPERVISED BY
APPROVED: CHIEF, DESIGN BRANCH
APPROVED: Charles E. Hipp CHIEF, ENGINEERING DIVISION
DATE JAN. 1970
SCALE
UNIT NO. DACW45-70-B-0054
APPROVED: C. P. Sundergrass DEPUTY CHIEF ENGINEER
DRAWING NUMBER SHEET PC6 - 40E10





DETAIL

NOTES:

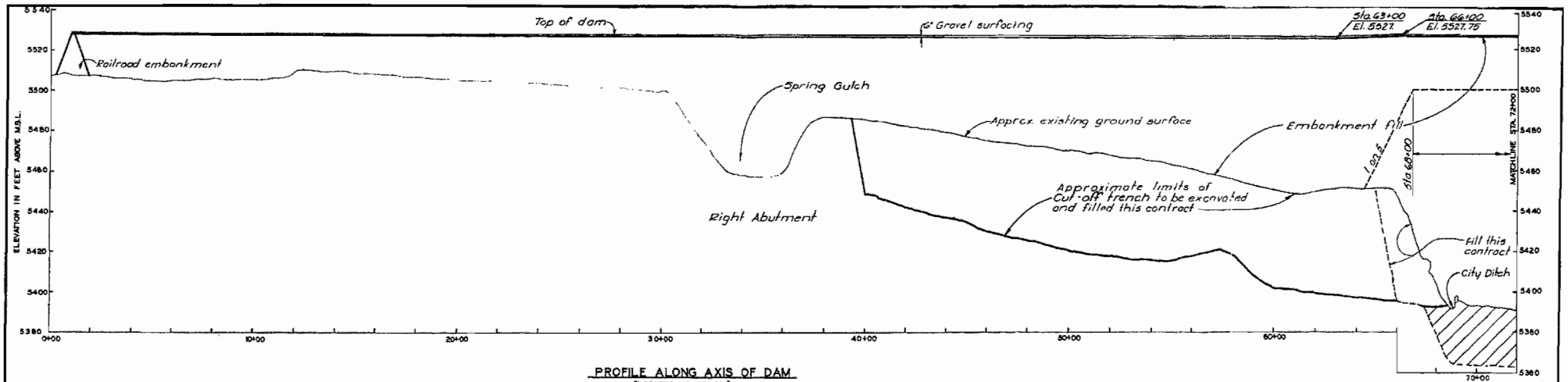
1. For General Notes and Legend, see dwg 40E8.
2. Area D-D is construction area for Service Bridge by others, see section 1 area use, for coordination of work.
3. For grading of the Downstream Outlet Works Channel, see Dwg. E 23.1 P/3.5.

SCALE 1 INCH = 100 FEET
100 0 100

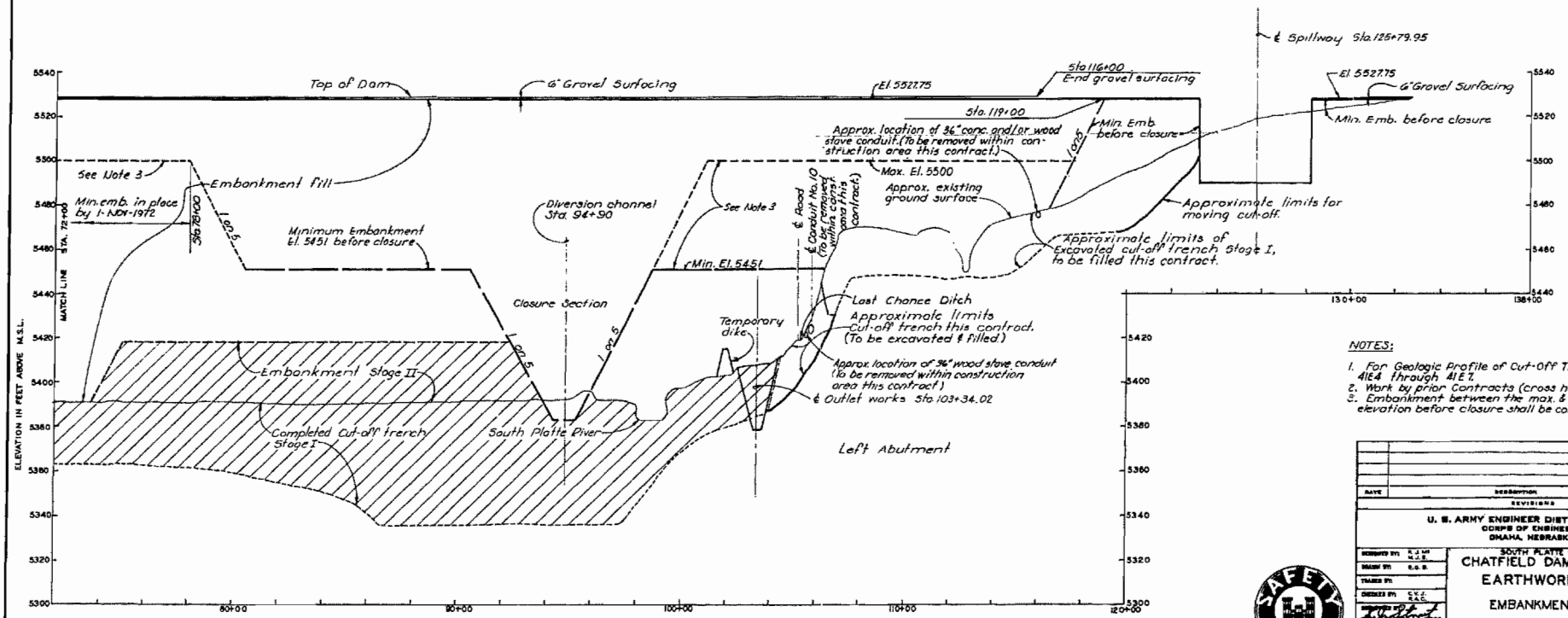
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EARTHWORK STAGE III
EMBANKMENT GRADING PLAN
SHEET 4

DESIGNED BY: R. J. M.
DRAWN BY: J. N. W.
TRACED BY:
CHECKED BY: G. V. A.
SUBMITTED BY: Chief, Design Section
APPROVED: Chief, Design Branch
APPROVED: Chief, Topographic Branch
APPROVED: Col. C. L. District Engineer
DATE: JAN. 1970
SCALE AS SHOWN
SPEC. NO. DACW45-70-B-0036
DRAWING NUMBER
SHEET PC6-40E11



PROFILE ALONG AXIS OF DAM
(LOOKING UPSTREAM)



PROFILE ALONG AXIS OF DAM
(LOOKING UPSTREAM)

SCALE: VERT. 1 INCH = 20 FEET
HORIZ. 1 INCH = 200 FEET

NOTES:

1. For Geologic Profile of Cut-Off Trench, see dwgs. 41E4 through 41E7.
2. Work by prior Contracts (cross hatched).
3. Embankment between the max. & min. embankment elevation before closure shall be completed as directed.

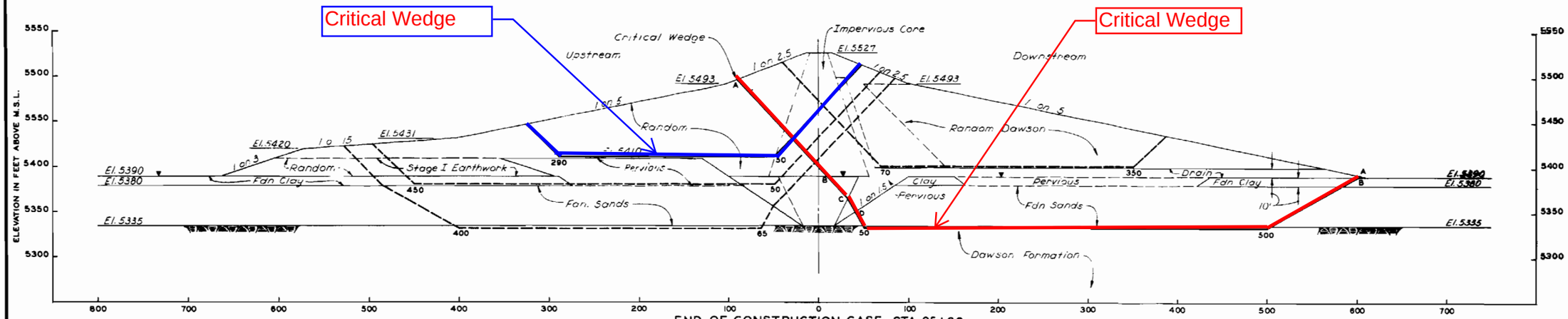
DATE	DESCRIPTION	MADE	APP'D
	REVISIONS		

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EARTHWORK - STAGE III
EMBANKMENT & PROFILE

DESIGNED BY: R.J.M. M.J.S.
DRAWN BY: E.G.B.
TRACED BY:
CHECKED BY: C.K.Z. R.A.S.
SUBMITTED BY: Chief, Div. Design Branch
APPROVED: Chief, Div. Design Branch
APPROVED: Chief, Div. Design Branch
DATE: NOV. 1971
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.



END OF CONSTRUCTION CASE - STA. 95+00

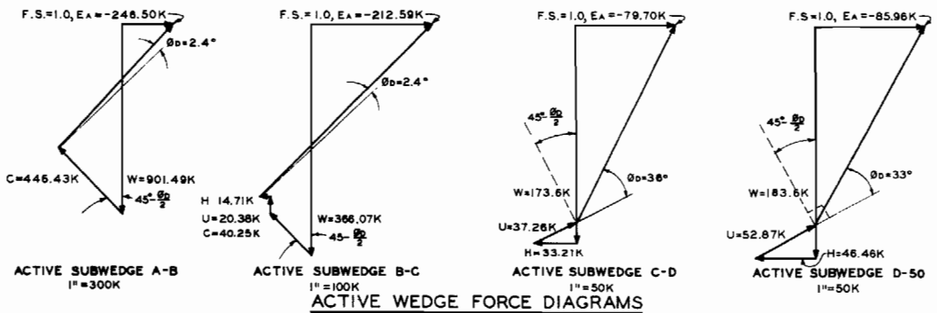
SCALE: 1 INCH = 50 FEET

FACTORS OF SAFETY UPSTREAM				
ELEVATION OF FAILURE PLANE	ACTIVE WEDGE DISTANCE FROM EMB. ℄	PASSIVE WEDGE DISTANCE FROM EMB. ℄	FACTORS OF SAFTY	
			NORMAL	EARTHQUAKE
5410	50	290	2.62	1.82*
5390	50	450	2.71	1.84
5335	65	400	2.64	1.75

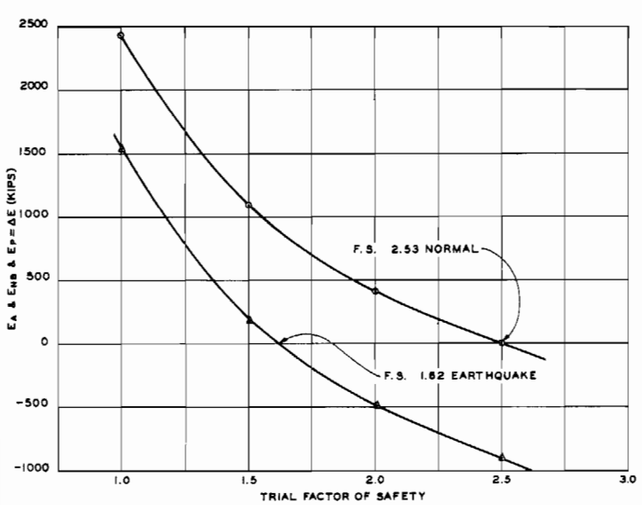
* CRITICAL

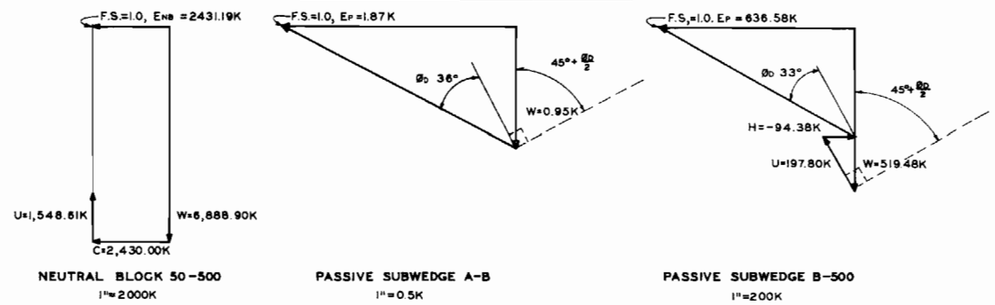
FACTORS OF SAFETY DOWNSTREAM				
ELEVATION OF FAILURE PLANE	ACTIVE WEDGE DISTANCE FROM EMB. ℄	PASSIVE WEDGE DISTANCE FROM EMB. ℄	FACTORS OF SAFETY	
			NORMAL	EARTHQUAKE
5400	70	350	2.67	1.90
5335	50	500	2.53	1.62*

*CRITICAL



ACTIVE WEDGE FORCE DIAGRAMS





NEUTRAL BLOCK AND PASSIVE WEDGE FORCE DIAGRAMS

NOTES:

1. Net Hydrostatic Force is perpendicular to vertical sides of subwedge or block.
2. Seismic coefficient = 0.1g
3. Wedges and force diagrams shown are for a trial F.S. = 1.0. Failure surfaces and force diagrams are slightly different for other trial F.S.'s due to Øb and c
4. All stability computations performed by R.C.A. 301 Computer - Program No. 41-R3-1302C.
5. Critical wedge shown by solid line.

NOMENCLATURE

W = WEIGHT OF WEDGE OR BLOCK
H = NET HYDROSTATIC FORCE
U = UPLIFT ON FAILURE PLANE
C = (COHESION ÷ TRIAL F.S.) × LENGTH OF PLANE
Øb = ARCTAN TAN Ø ÷ TRIAL F.S.
F.S. = SHEAR STRENGTH ASSUMED / SHEAR STRENGTH NEEDED FOR EQUILIBRIUM

ADOPTED SHEAR STRENGTH						
MATERIAL	IN PLACE WEIGHT	SAT'D. WEIGHT	SUBM. WEIGHT	UNCONSOLIDATED UNDRAINED - "Q"		
	#/FT³	#/FT	#/FT	TAN Ø	Ø	COH-T/SF
EMBANKMENT						
Impervious	120.0	126.0	63.6	0.042	2.4	1.50
Random	120.0	126.0	63.6	0.042	2.4	1.50
Pervious	130.0	136.0	73.6	0.73	36.1	0.0
Dawson FN.	120.0	126.0	63.6	0.00	0	2.0
FOUNDATION						
Clay		118.0	55.6	0.00	0	0.28
Sand		125.0	62.6	0.65	33.0	0.00
Dawson	130.0	135.0	72.6	0.00	0	2.70

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

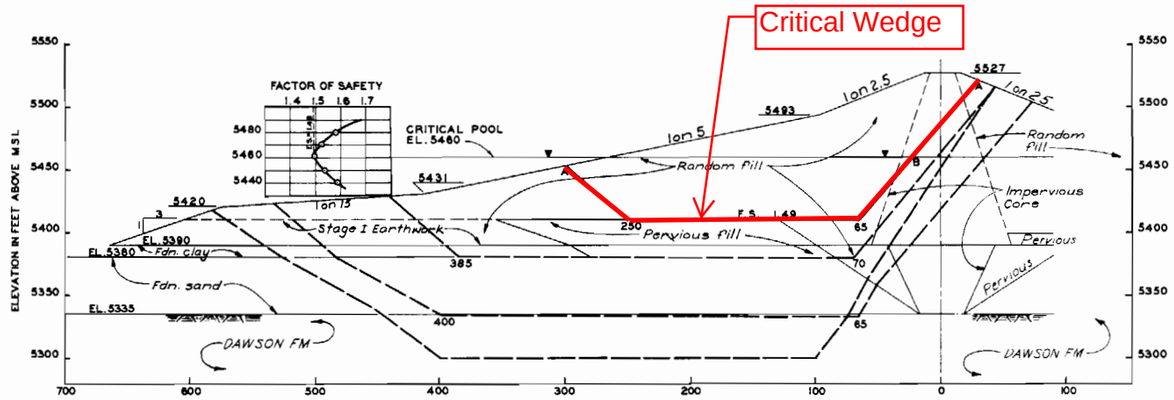
DESIGNED BY: L. G. S.
DRAWN BY: R. G. S.
TRACED BY:
CHECKED BY: L. G. S.
SUBMITTED BY: [illegible]
APPROVED: [illegible] CHIEF, FDN. & MTLS. BRANCH
APPROVED: [illegible] CHIEF ENGINEERING DIVISION
APPROVED: [illegible] COL. C. E. DISTRICT ENGINEER

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION
STABILITY ANALYSIS
END OF CONSTRUCTION CASE
STA. 95+00

DATE: DEC. 1968
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

CHATFIELD RE-ALLOCATION STUDY PLATE B-1



PARTIAL POOL STA. 95+00

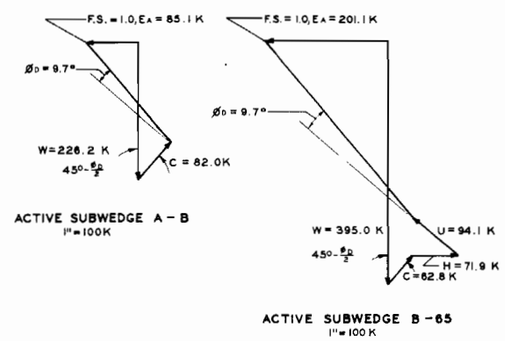
SCALE: 1 INCH = 50 FEET
50' 0 50'

ELEV. OF FAILURE PLANE	ACTIVE WEDGE	PASSIVE WEDGE	FACTORS OF SAFETY POOL ELEVATIONS 5420 NORM.	5420 E.Q.	5431 NORM.	5431 E.Q.	5440 NORM.	5440 E.Q.	5450 NORM.	5450 E.Q.	5460 NORM.	5460 E.Q.	5470 NORM.	5470 E.Q.	5480 NORM.	5480 E.Q.
5410	65	250					1.59	1.12	1.53	1.08	1.49*	1.04	1.52	1.04	1.58	1.05
5380	70	385					1.96	1.31	1.95	1.28	1.94	1.25				
5335	65	400					2.09	1.31	2.12	1.30	2.18	1.30	*R* STRENGTH			
5300	100	400	1.78	1.12	1.74	1.08	1.76	1.08	1.79	1.07	1.84	1.07	*S* STRENGTH			

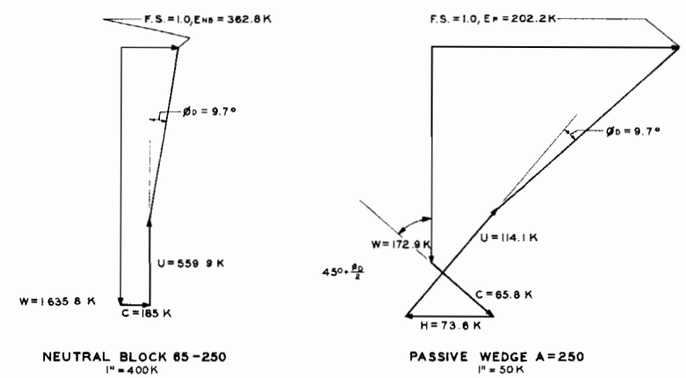
* Critical

ADOPTED DESIGN VALUES FOR EMBANKMENT STABILITY									
MATERIAL	IN PLACE WEIGHT #/FT.³	SAT'D WEIGHT #/FT.³	SUBM. WEIGHT #/FT.³	CONSOLIDATED UNDRAINED *R* TAN Ø	Ø	COH-TSF	CONSOLIDATED DRAINED *S* TAN Ø	Ø	COH-TSF
EMBANKMENT									
Impervious	120.0	126.0	63.6	0.17	9.7	0.50	0.45	24.3	0.0
Random	120.0	126.0	63.6	0.17	9.7	0.50	0.45	24.3	0.0
Pervious	130.0	136.0	73.6	0.73	36.1	0.00	0.73	36.1	0.0
Dawson Fm.	120.0	126.0	63.6	0.20	11.3	0.40	0.41	22.3	0.0
FOUNDATION									
Clay		118.0	55.6	0.15	8.5	0.30	0.38	20.8	0.0
Sand		125.0	62.6	0.65	33.0	.00	0.65	33.0	0.0
Dawson	130.0	135.0	72.6	0.35	19.3	0.40	0.27*	15.0*	0.0*

* Used in lieu of "S" strength

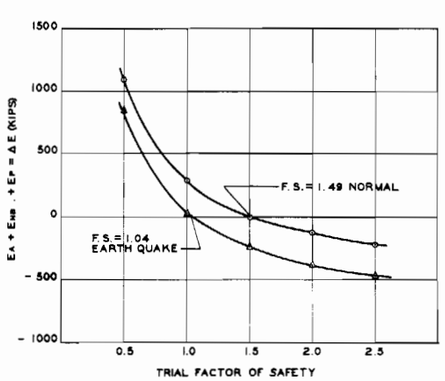


ACTIVE WEDGE FORCE DIAGRAMS



NEUTRAL BLOCK AND PASSIVE WEDGE FORCE DIAGRAMS

NOTES:
For notes see plate B-73



NOMENCLATURE

W = WEIGHT OF WEDGE OR BLOCK
H = NET HYDROSTATIC FORCE
U = UPLIFT ON FAILURE PLANE
C = (COHESION + TRIAL F.S.) × LENGTH OF PLANE
ϕ_D = ARCTAN TAN ϕ ÷ TRIAL F.S.
F.S. = SHEAR STRENGTH ASSUMED / SHEAR STRENGTH NEEDED FOR EQUILIBRIUM

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D
	REVISIONS		

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

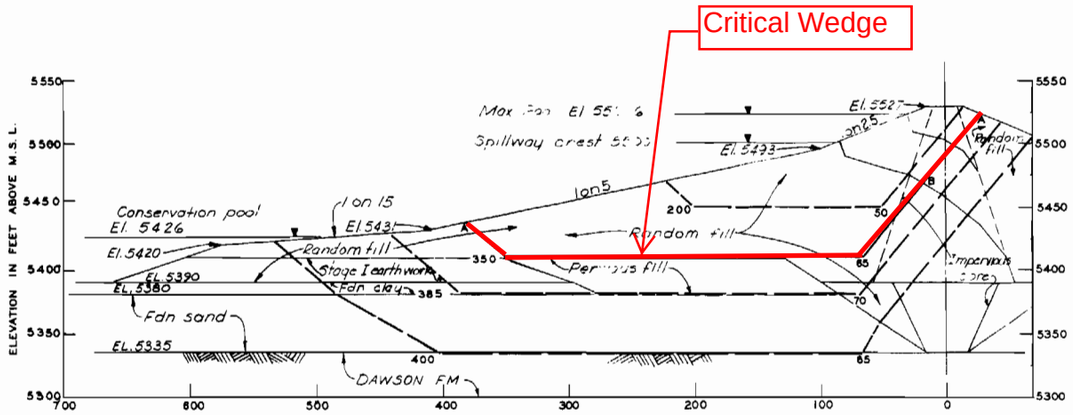
DESIGNED BY: L.G.S
DRAWN BY: J.M.F
TRACED BY:
CHECKED BY: L.G.S
SUBMITTED BY: Chief, Div. Hydraulic Div.
APPROVED: Chief, Div. H & M. Br.
APPROVED: Chief, Hydraulic Division

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION
STABILITY ANALYSIS
PARTIAL POOL CASE
STA. 95 + 00

DATE: DEC 1968
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

APPROVED: COL. G. E., DISTRICT ENGINEER

CHATFIELD RE-ALLOCATION STUDY PLATE B-2

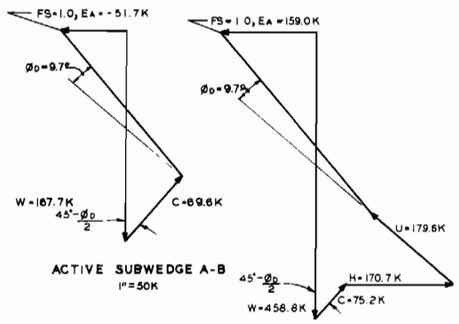


SUDDEN DRAWDOWN STA. 95+00

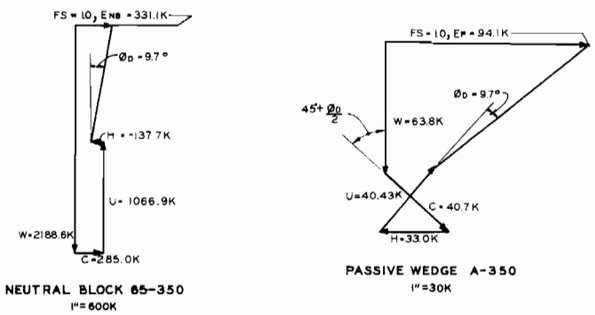
SCALE: 1 INCH = 50 FEET
50' 0 50'

FACTORS OF SAFETY						
EL. OF FAILURE PLANE	ACTIVE WEDGE	PASSIVE WEDGE	FACTORS OF SAFETY			
			CREST		MAX.	
			NORMAL	E.Q.	NORMAL	E.Q.
5450	50	200	1.57	1.12	1.50	–
5410	65	350	1.33*	0.92	1.23	–
5380	70	385	1.56	1.05	1.47	–
5335	65	400	1.78	1.14	1.68	–
Req'd F.S.			1.20	1.0	1.0	–

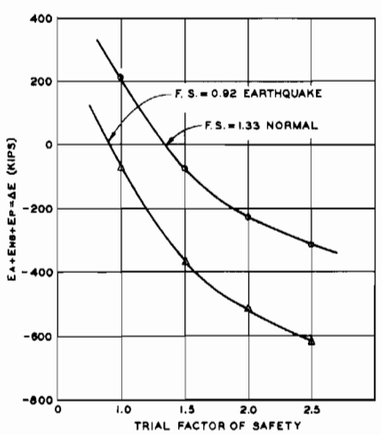
*Critical



ACTIVE WEDGE FORCE DIAGRAMS



NEUTRAL BLOCK AND PASSIVE WEDGE FORCE DIAGRAMS



ADOPTED SHEAR STRENGTHS						
MATERIAL	IN PLACE WEIGHT	SAT'D WEIGHT	SUBM WEIGHT	CONSOLIDATED UNDRAINED-"R"		
	#/FT.³	#/FT.³	#/FT.³	TAN Ø	Ø	COHES. T/FT²
EMBANKMENT						
Impervious	120.0	126.0	63.6	0.17	9.7	0.50
Random	120.0	126.0	63.6	0.17	9.7	0.50
Pervious	130.0	136.0	73.6	0.73	36.1	0.00
Dawson FM.	120.0	126.0	63.6	0.20	11.3	0.40
FOUNDATION						
Clay		118.0	55.6	0.15	8.5	0.30
Sand		125.0	62.6	0.65	33.0	0.0
Dawson	130.0	135.0	72.6	0.35	19.3	0.40

NOMENCLATURE

W = WEIGHT OF WEDGE OR BLOCK
H = NET HYDROSTATIC FORCE
U = UPLIFT ON FAILURE PLANE
C = (COHESION ÷ TRIAL F.S.) × LENGTH OF PLANE
ϕ_D = ARCTAN TAN Ø ÷ TRIAL F.S.
F.S. = SHEAR STRENGTH ASSUMED / SHEAR STRENGTH NEEDED FOR EQUILIBRIUM

NOTE:
1. For notes, see plate B-73

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

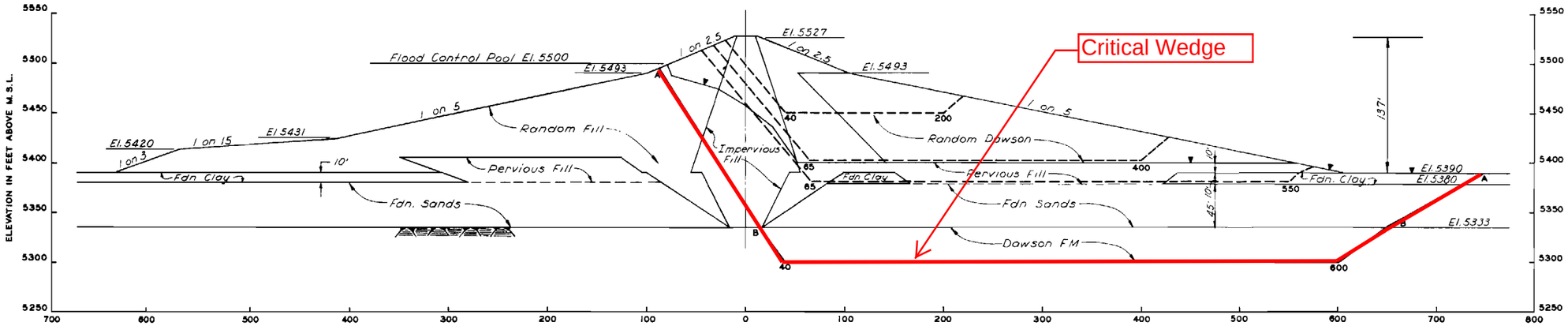
DESIGNED BY: L. G. S.
DRAWN BY: R. G. H.
TRACED BY:
CHECKED BY: L. G. S.
SUBMITTED BY: Chief Eng. Div. for Construction
APPROVED: Chief Fdn. & Mtls. Branch
APPROVED: Chief Engineering Division
APPROVED: Col. S. E. District Engineer

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION

STABILITY ANALYSIS
SUDDEN DRAWDOWN CASE
STA. 95+00

DATE: DEC. 1968
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

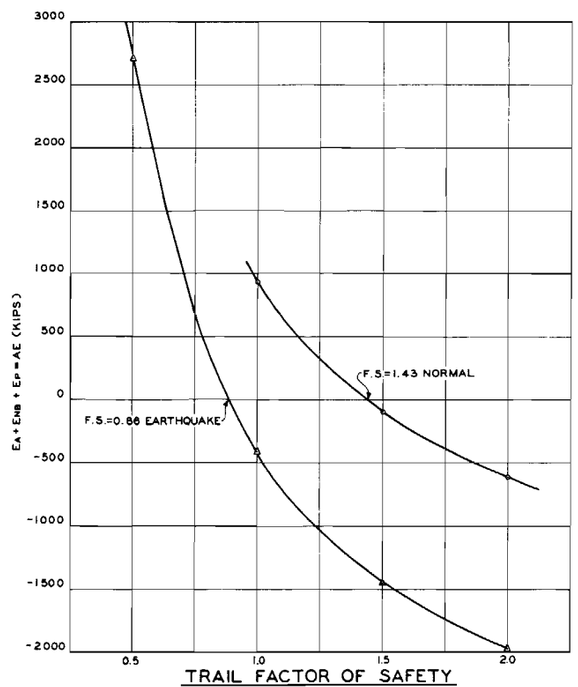


STEADY SEEPAGE STA. 95+00

SCALE: 1 INCH = 50 FEET (50' 0 50')

EL. OF FAILURE PLANE	ACTIVE WEDGE	PASSIVE WEDGE	FACTORS OF SAFETY					
			R. STRENGTH		S. STRENGTH		AVERAGE	
			NORMAL	E.Q.	NORMAL	E.Q.	NORMAL	E.Q.
5450	40 65	200 315	1.82	1.32	1.84	1.34	1.83	1.83
5400	65 85	400 565	1.63	1.13	2.13	1.48	1.88	1.31
5380	65	550	2.49	1.68	2.73	1.84	2.61	1.76
5300	40	600	1.98	1.26	*1.43	0.86		

* Critical



TRAIL FACTOR OF SAFETY

APOPTED SHEAR STRENGTHS									
MATERIAL	IN PLACE WEIGHT	SAT'D. WEIGHT	SUBM. WEIGHT	CONSOLIDATED UNDRAINED - "R"			CONSOLIDATED DRAINED - "S"		
	#/FT.³	#/FT.³	#/FT.³	TAN ϕ	ϕ	COH-T/SF	TAN ϕ	ϕ	COH-T/SF
EMBANKMENT									
Impervious	120.0	126.0	63.6	0.17	9.7	0.50	0.45	24.3	0.0
Random	120.0	126.0	63.6	0.17	9.7	0.50	0.45	24.3	0.0
Pervious	130.0	136.0	73.6	0.73	36.1	0.00	0.73	36.1	0.0
Dawson FM.	120.0	126.0	63.6	0.20	11.3	0.40	0.41	22.3	0.0
FOUNDATION									
Clay		118.0	55.6	0.15	8.5	0.30	0.38	20.8	0.0
Sand		125.0	62.6	0.65	33.0	00	0.65	33.0	0.0
Dawson	130.0	135.0	72.6	0.35	19.3	0.40	0.27*	15.0*	0.0*

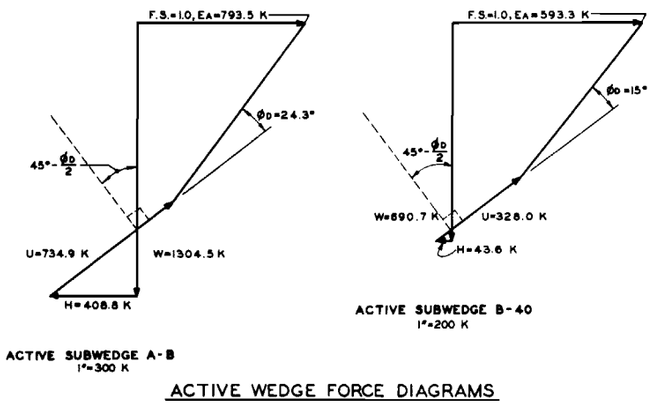
* Used in lieu of "S" strength

NOMENCLATURE

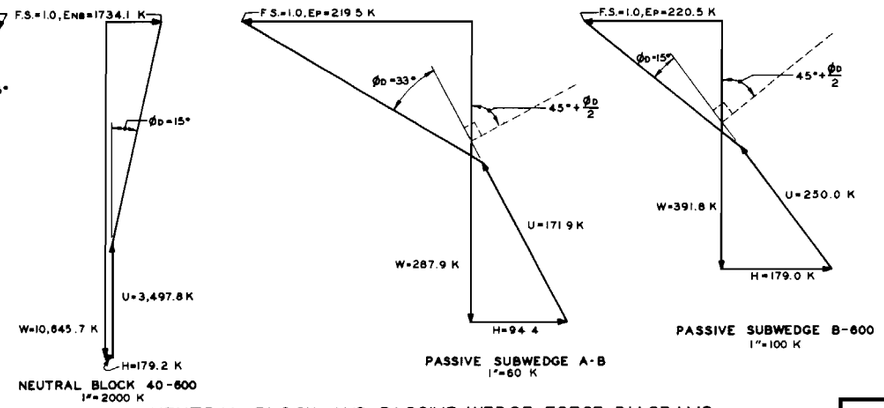
W = WEIGHT OF WEDGE OR BLOCK
H = NET HYDROSTATIC FORCE
U = UPLIFT ON FAILURE PLANE
C = (COHESION + TRIAL F.S.) × LENGTH OF PLANE
ϕ_D = ARCTAN TAN ϕ ÷ TRIAL F.S.
F.S. = SHEAR STRENGTH ASSUMED / SHEAR STRENGTH NEEDED FOR EQUILIBRIUM

NOTE:
1. For notes, see plate B-73

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.



ACTIVE WEDGE FORCE DIAGRAMS



NEUTRAL BLOCK AND PASSIVE WEDGE FORCE DIAGRAMS

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

DATE	DESCRIPTION	MADE	APPR'D
	REVISIONS		

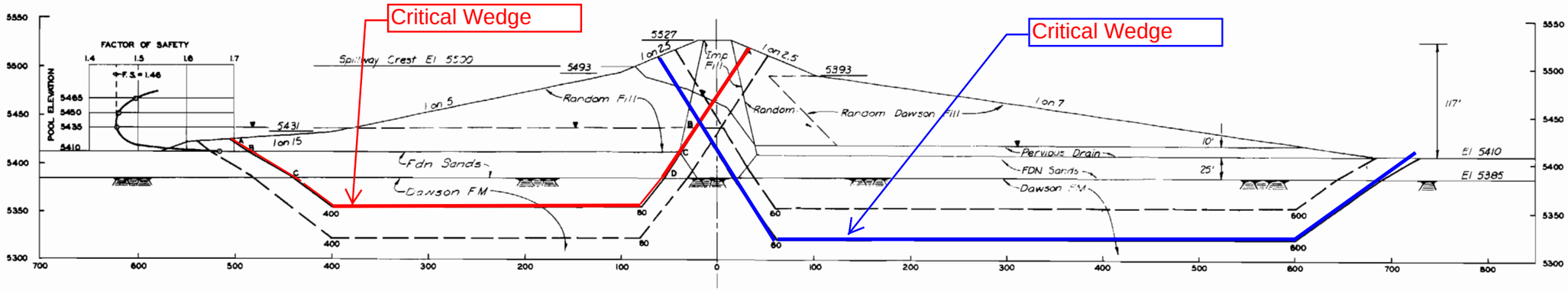
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: L. G. S.
DRAWN BY: R. M.
TRACED BY:
CHECKED BY: L. G. S.
SUBMITTED BY: [signature] CHIEF, ENGINEERING DIV.
APPROVED: [signature] CHIEF, FDN. & EARTH BRANCH
APPROVED: [signature] COL., C. E., DISTRICT ENGINEER

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION
STABILITY ANALYSIS
STEADY SEEPAGE CASE
STA. 95+00

APPROVED: [signature] CHIEF, ENGINEERING DIVISION
DATE: DEC 1968
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

CHATFIELD RE-ALLOCATION STUDY PLATE B-4



PARTIAL POOL AND STEADY SEEPAGE - "S" STRENGTHS

OUTLET WORKS STA. 104 + 35

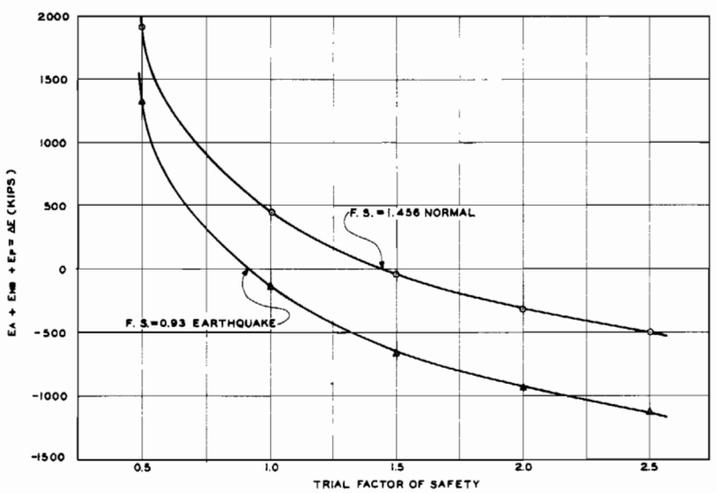
SCALE: 1 INCH = 50 FEET

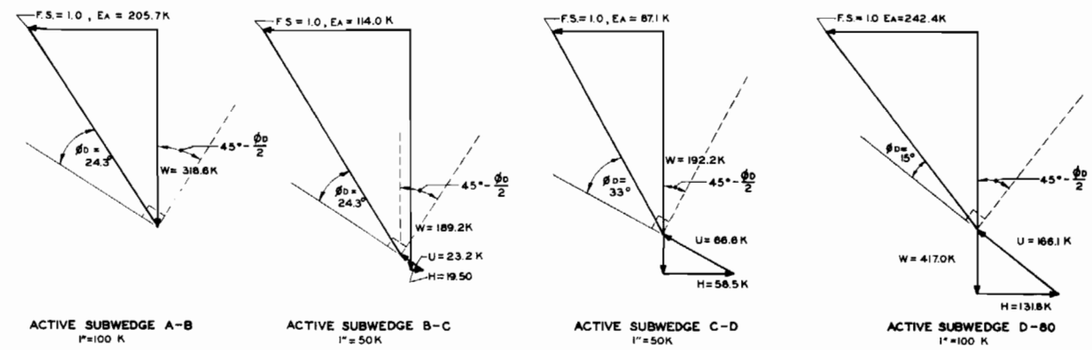
FACTORS OF SAFETY UPSTREAM PARTIAL POOL - "S" STRENGTH										
EL. OF FAILURE PLANE	ACTIVE WEDGE	PASSIVE WEDGE	FACTORS OF SAFETY POOL ELEVATION							
			5465		5450		5435		5410	
			NORM	E.Q.	NORM	E.Q.	NORM	E.Q.	NORM	E.Q.
5353	80	400	1.495	0.88	1.460	0.90	*1.456	*0.93	1.67	1.08
5320	100	400	1.57	0.90	1.51	0.91	—	—	1.64	1.05
Req'd. F.S.			1.50	1.0						

* Critical

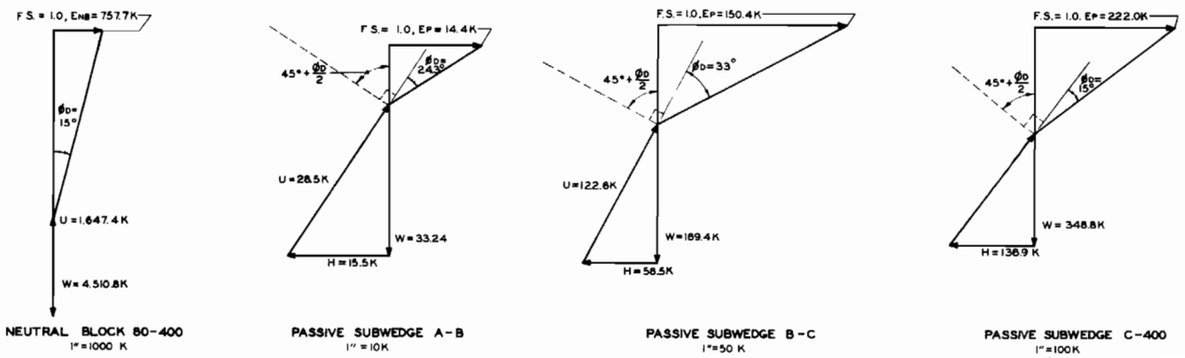
FACTORS OF SAFETY DOWNSTREAM STEADY SEEPAGE - "S" STRENGTH				
EL. OF FAILURE PLANE	ACTIVE WEDGE	PASSIVE WEDGE	FACTORS OF SAFETY	
			NORMAL	E.Q.
5353	60	600	1.62	0.96
5320	60	600	1.58 *	0.92 *
Req'd. F.S.			1.50	1.0

* Critical





ACTIVE WEDGE FORCE DIAGRAMS



NEUTRAL BLOCK AND PASSIVE WEDGE FORCE DIAGRAMS

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

ADOPTED SHEAR STRENGTH									
MATERIAL	IN PLACE WEIGHT		SAT'D WEIGHT		SUBM. WEIGHT		CONSOLIDATED DRAINED - "S"		
	#/FT³	T/FT³	#/FT³	#/FT³	#/FT³	T/FT³	TAN ø	ø	COH. T/SF
EMBANKMENT									
Impervious	120.0	0.060	126.0	0.063	63.6	.0318	0.45	24.3	0.0
Random	120.0	0.060	126.0	0.063	63.6	.0318	0.45	24.3	0.0
Pervious	130.0	0.065	136.0	0.068	73.6	.0368	0.73	36.1	0.0
Dawson FM	120.0	0.060	126.0	0.065	63.6	.0318	0.41	22.3	0.0
FOUNDATION									
Clay			118.0	0.059	55.6	.0278	0.38	20.8	0.0
Sand			125.0	0.063	62.6	.0313	0.65	33.0	0.0
Dawson	130.0		135.0	0.0675	72.6	.0363	0.27*	15.0*	0.0*

* Used in lieu of "s" strength

NOMENCLATURE

W = WEIGHT OF WEDGE OR BLOCK
H = NET HYDROSTATIC FORCE
U = UPLIFT ON FAILURE PLANE
C = (COHESION ÷ TRIAL F.S.) × LENGTH OF PLANE
$ø_D$ = ARCTAN TAN ø ÷ TRIAL F.S.
F.S. = SHEAR STRENGTH ASSUMED / SHEAR STRENGTH NEEDED FOR EQUILIBRIUM

Note:
1. For notes refer to Plate B-73

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

DATE	DESCRIPTION	MADE	APPR'D
	REVISIONS		

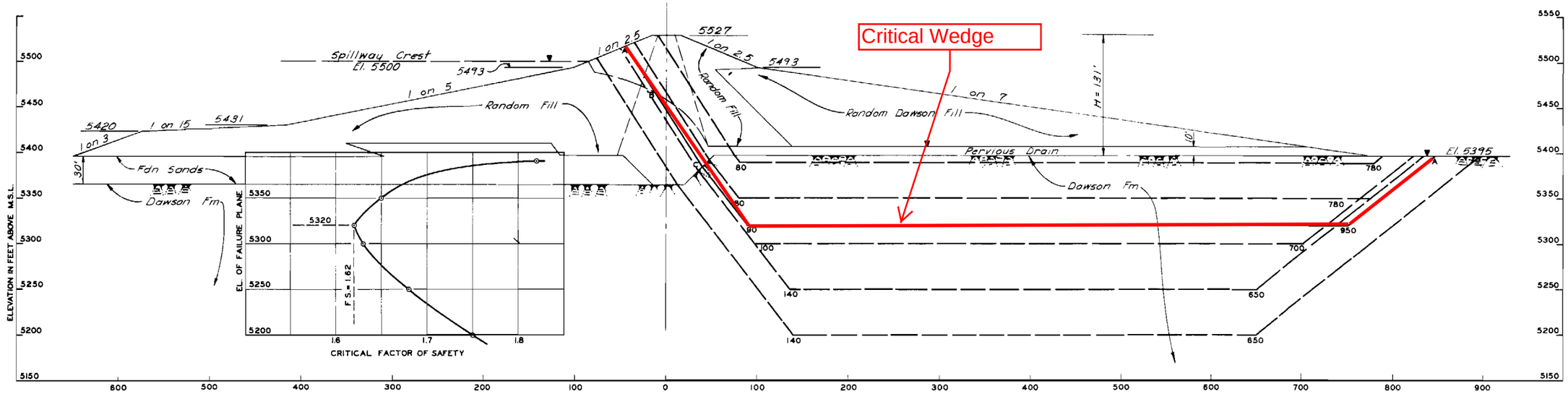
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: L G S
DRAWN BY: J F P
TRACED BY:
CHECKED BY: L G S
SUBMITTED BY: SUPERVISORY CIVIL ENGR. SEC.
APPROVED: DIST. ENG. & MT. BRANCH
APPROVED: Charles L. Hipp, CHIEF ENGINEERING DIVISION
APPROVED: COL. G. E., DISTRICT ENGINEER

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION
STABILITY ANALYSIS
PARTIAL POOL AND STEADY SEEPAGE CASES
OUTLET WORKS - STA. 104+35

DATE: DEC 1968
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

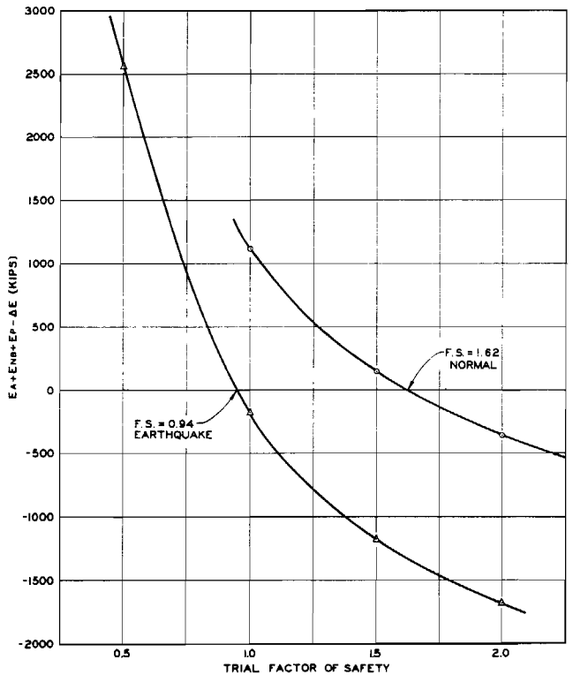
CHATFIELD RE-ALLOCATION STUDY PLATE B-5



STEADY SEEPAGE-"S" STRENGTHS

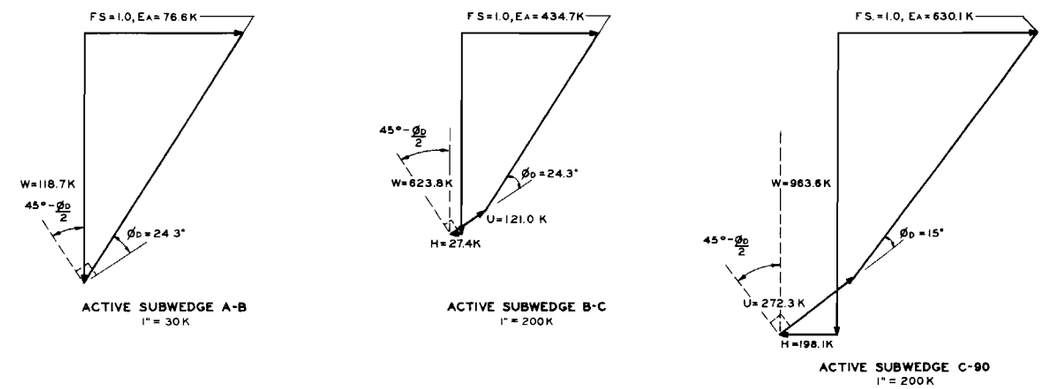
RT. VALLEY-STA. 68+50

SCALE: 1 INCH = 50 FEET



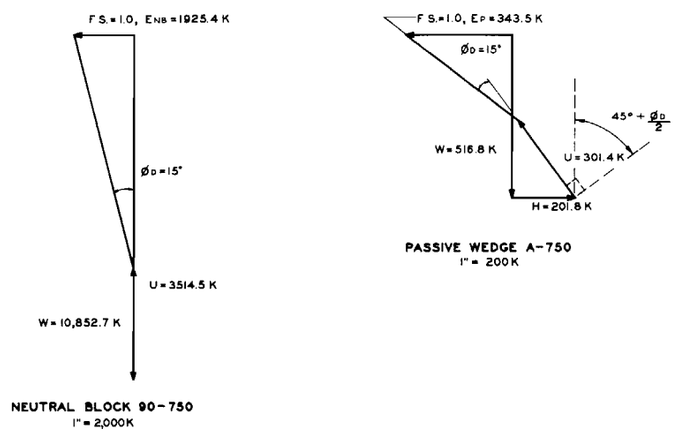
EL. OF FAILURE PLANE	ACTIVE WEDGE	PASSIVE WEDGE	FACTOR OF SAFETY	
			NORM.	E.Q
5390	80	780	1.82	1.12
5350	80	780	1.65	0.97
5320	90	750	1.62 *	0.94 *
5300	100	700	1.63	0.94
5250	140	650	1.68	0.97
5200	140	650	1.75	0.98
Reqd. Factor of Safety			1.50	1.0

*Critical



ACTIVE WEDGE FORCE DIAGRAMS

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.



NEUTRAL BLOCK AND PASSIVE WEDGE FORCE DIAGRAMS

NOMENCLATURE

W = WEIGHT OF WEDGE OR BLOCK
H = NET HYDROSTATIC FORCE
U = UPLIFT ON FAILURE PLANE
C = (COHESION + TRIAL F.S.) × LENGTH OF PLANE
ϕ_D = ARCTAN TAN ϕ ÷ TRIAL F.S.
F.S. = SHEAR STRENGTH ASSUMED / SHEAR STRENGTH NEEDED FOR EQUILIBRIUM

NOTE:
1 For NOTES, see Plate B-73

DATE	DESCRIPTION	MADE	APPR'D
	REVISIONS		

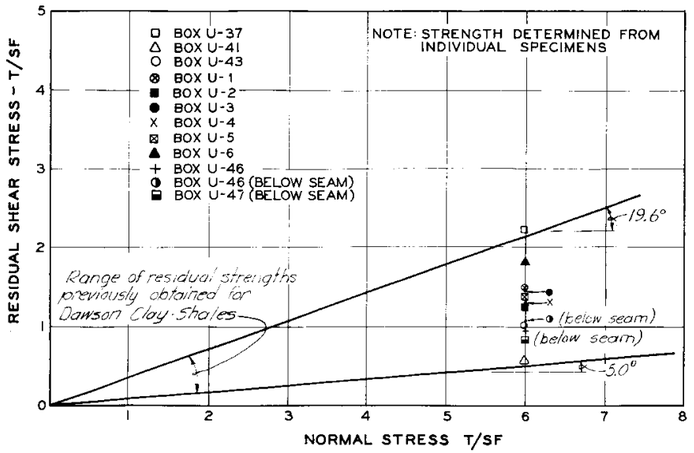
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: L G S
DRAWN BY: E J G
TRACED BY:
CHECKED BY: L G S
SUBMITTED BY: CHIEF, DAM & RESERVOIR SECTION

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION
STABILITY ANALYSIS
STEADY SEEPAGE CASE
RIGHT VALLEY-STA. 68+50

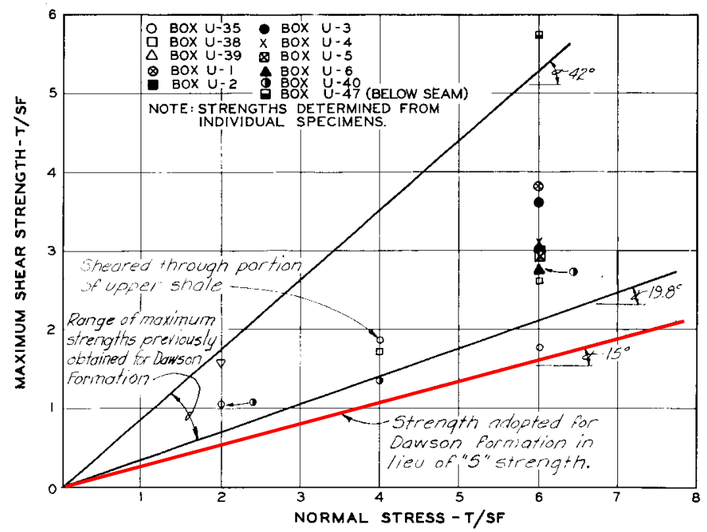
APPROVED: CHIEF FDN & MTLS BRANCH
APPROVED: Charles L. Hipp, CHIEF ENGINEERING DIVISION
DATE: DEC. 1966
APPROVED: COL. C. E., DISTRICT ENGINEER
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.



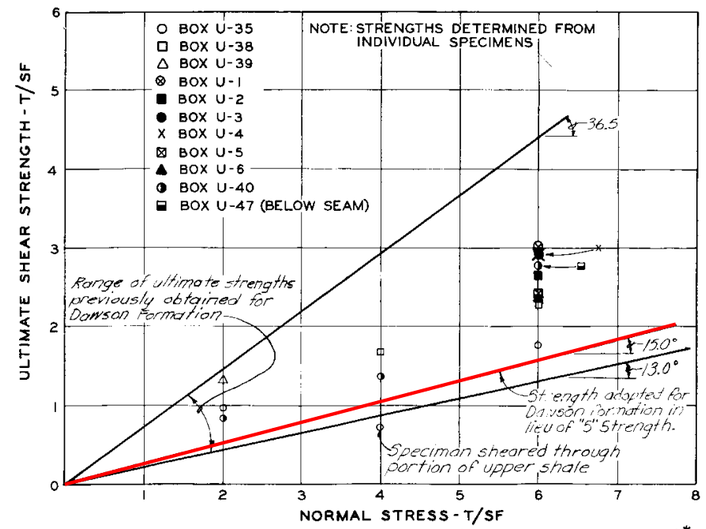
SUMMARY OF RESIDUAL DIRECT SHEAR TESTS ON SOFT SEAM

FIGURE 1



SUMMARY OF DIRECT SHEAR TESTS (MAXIMUM STRENGTH) ON SOFT SEAM MATERIAL.

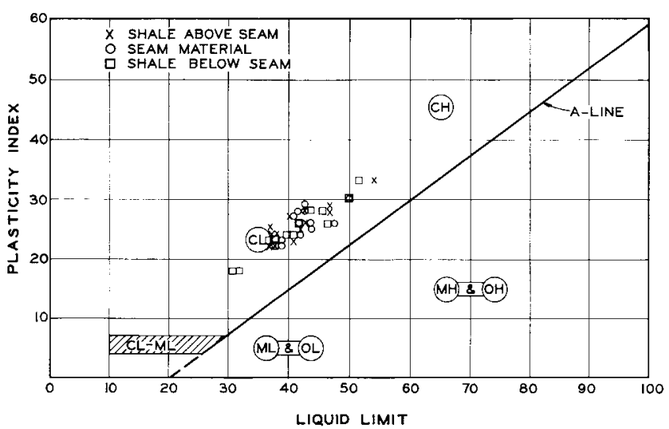
FIGURE 2



SUMMARY OF DIRECT SHEAR TESTS (ULTIMATE STRENGTH)* ON SOFT SEAM MATERIAL.

FIGURE 3

*NOTE: ULTIMATE STRENGTH IS THAT AFTER HORIZONTAL DEFORMATION OF 0.5 INCH IN DIRECT SHEAR.



PLASTICITY CHART

FIGURE 4

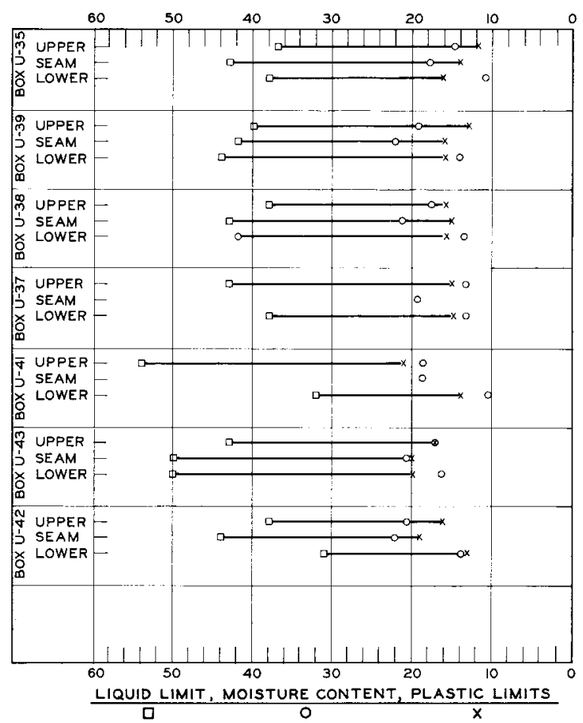


FIGURE 5

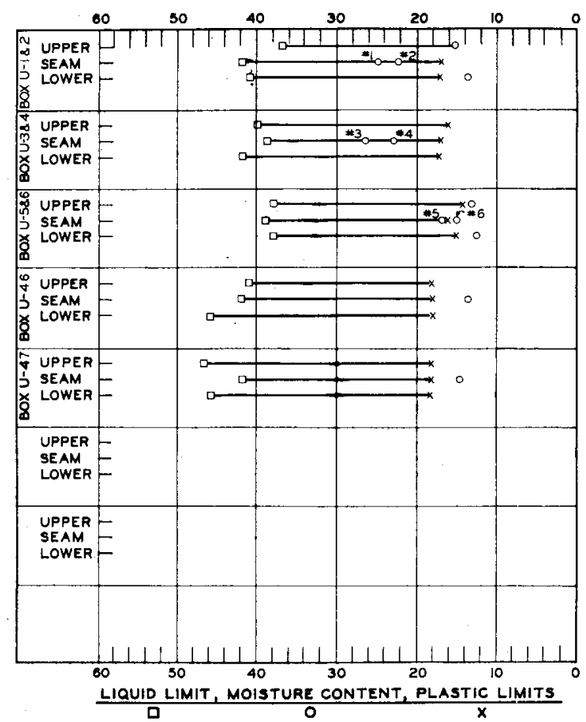


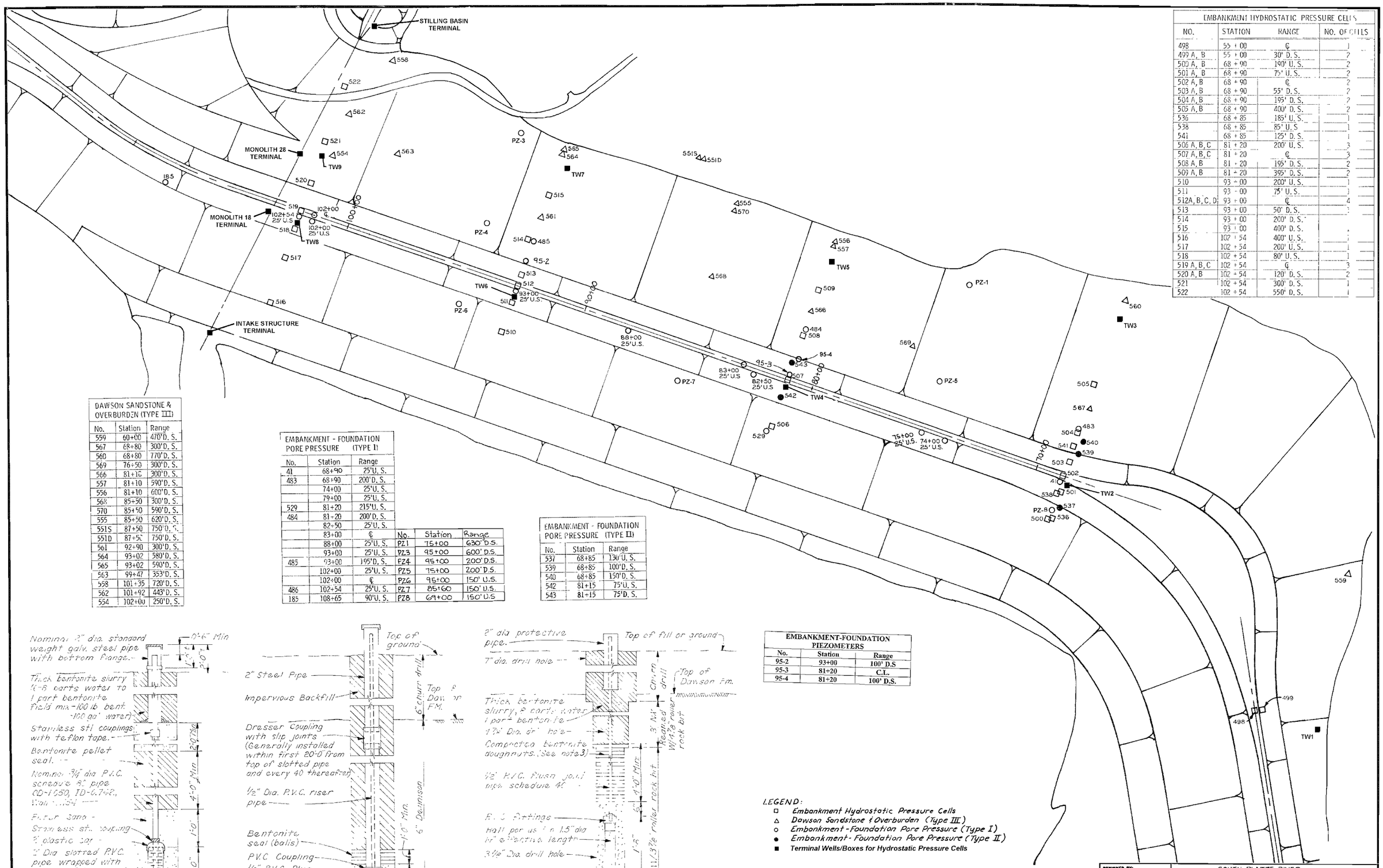
FIGURE 6

MOISTURE AND ATTERBERG LIMITS RELATIONSHIPS

NOTE:

1. Residual Tests on Boxes U-46 and U-47 were performed on precut samples; all other tests were performed on undisturbed samples.

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
EMBANKMENT AND EXCAVATION
UNDISTURBED DAWSON FORMATION
SUMMARIES OF DIRECT SHEAR TESTS
(RESIDUAL AND NORMAL) ON SOFT SEAM
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA.
OCT. 1970



EMBANKMENT HYDROSTATIC PRESSURE CELLS			
NO.	STATION	RANGE	NO. OF CELLS
498	55 + 00	℄	1
499 A, B	55 + 00	30' D. S.	2
500 A, B	68 + 90	190' U. S.	2
501 A, B	68 + 90	75' U. S.	2
502 A, B	68 + 90	℄	2
503 A, B	68 + 90	55' D. S.	2
504 A, B	68 + 90	195' D. S.	2
505 A, B	68 + 90	400' D. S.	2
536	68 + 85	185' U. S.	1
538	68 + 85	85' U. S	1
541	68 + 85	125' D. S.	1
506 A, B, C	81 + 20	200' U. S.	3
507 A, B, C	81 + 20	℄	3
508 A, B	81 + 20	195' D. S.	2
509 A, B	81 + 20	395' D. S.	2
510	93 + 00	200' U. S.	1
511	93 + 00	75' U. S.	1
512A, B, C, D	93 + 00	℄	4
513	93 + 00	50' D. S.	1
514	93 + 00	200' D. S.	1
515	93 + 00	400' D. S.	1
516	102 + 54	400' U. S.	1
517	102 + 54	200' U. S.	1
518	102 + 54	80' U. S.	1
519 A, B, C	102 + 54	℄	3
520 A, B	102 + 54	120' D. S.	2
521	102 + 54	300' D. S.	1
522	102 + 54	550' D. S.	1

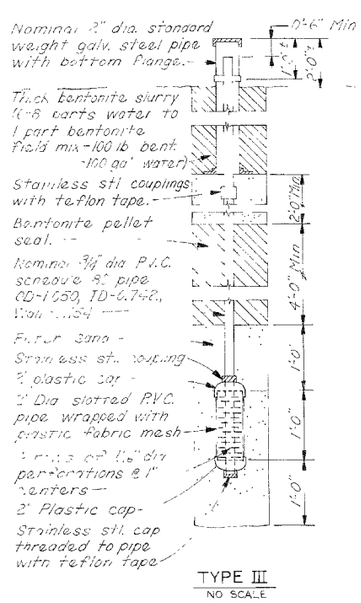
DAWSON SANDSTONE & OVERBURDEN (TYPE III)		
No.	Station	Range
559	60+00	470'D. S.
567	68+80	300'D. S.
560	68+80	770'D. S.
569	76+50	300'D. S.
566	81+10	300'D. S.
557	81+10	590'D. S.
556	81+10	600'D. S.
568	85+50	300'D. S.
570	85+50	590'D. S.
555	85+50	620'D. S.
551S	87+50	750'D. S.
551D	87+50	750'D. S.
561	92+90	300'D. S.
564	93+02	580'D. S.
565	93+02	590'D. S.
563	99+47	353'D. S.
558	101+35	720'D. S.
562	101+92	443'D. S.
554	102+00	250'D. S.

EMBANKMENT - FOUNDATION PORE PRESSURE (TYPE I)		
No.	Station	Range
41	68+90	25'U. S.
483	68+90	200'D. S.
	74+00	25'U. S.
	79+00	25'U. S.
529	81+20	215'U. S.
484	81+20	200'D. S.
	82+50	25'U. S.
	83+00	℄
	88+00	25'U. S.
	93+00	25'U. S.
485	93+00	195'D. S.
	102+00	25'U. S.
	102+00	℄
486	102+54	25'U. S.
185	108+65	90'U. S.

No.	Station	Range
PZ1	75+00	630'D.S.
PZ3	95+00	600' D.S.
PZ4	95+00	200'D.S.
PZ5	75+00	200'D.S.
PZ6	95+00	150' U.S.
PZ7	85+60	150' U.S.
PZ8	69+00	150' U.S

EMBANKMENT - FOUNDATION PORE PRESSURE (TYPE II)		
No.	Station	Range
537	68+85	130'U. S.
539	68+85	100'D. S.
540	68+85	150'D. S.
542	81+15	75'U. S.
543	81+15	75'D. S.

EMBANKMENT-FOUNDATION PIEZOMETERS		
No.	Station	Range
95-2	93+00	100' D.S
95-3	81+20	C.L.
95-4	81+20	100' D.S.



TYPE III
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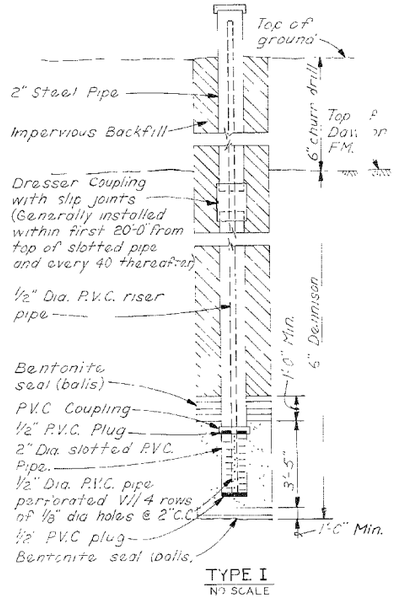

TYPE I
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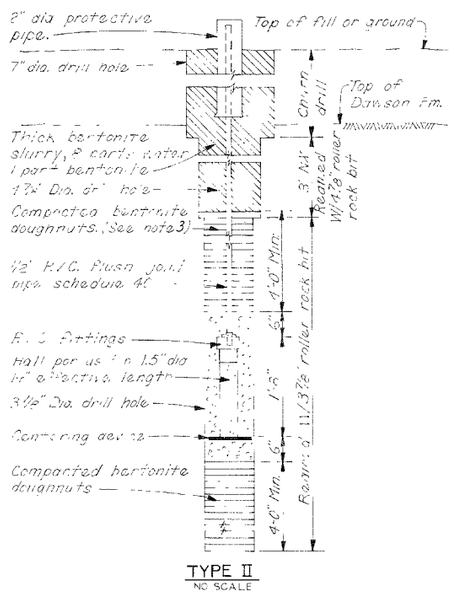
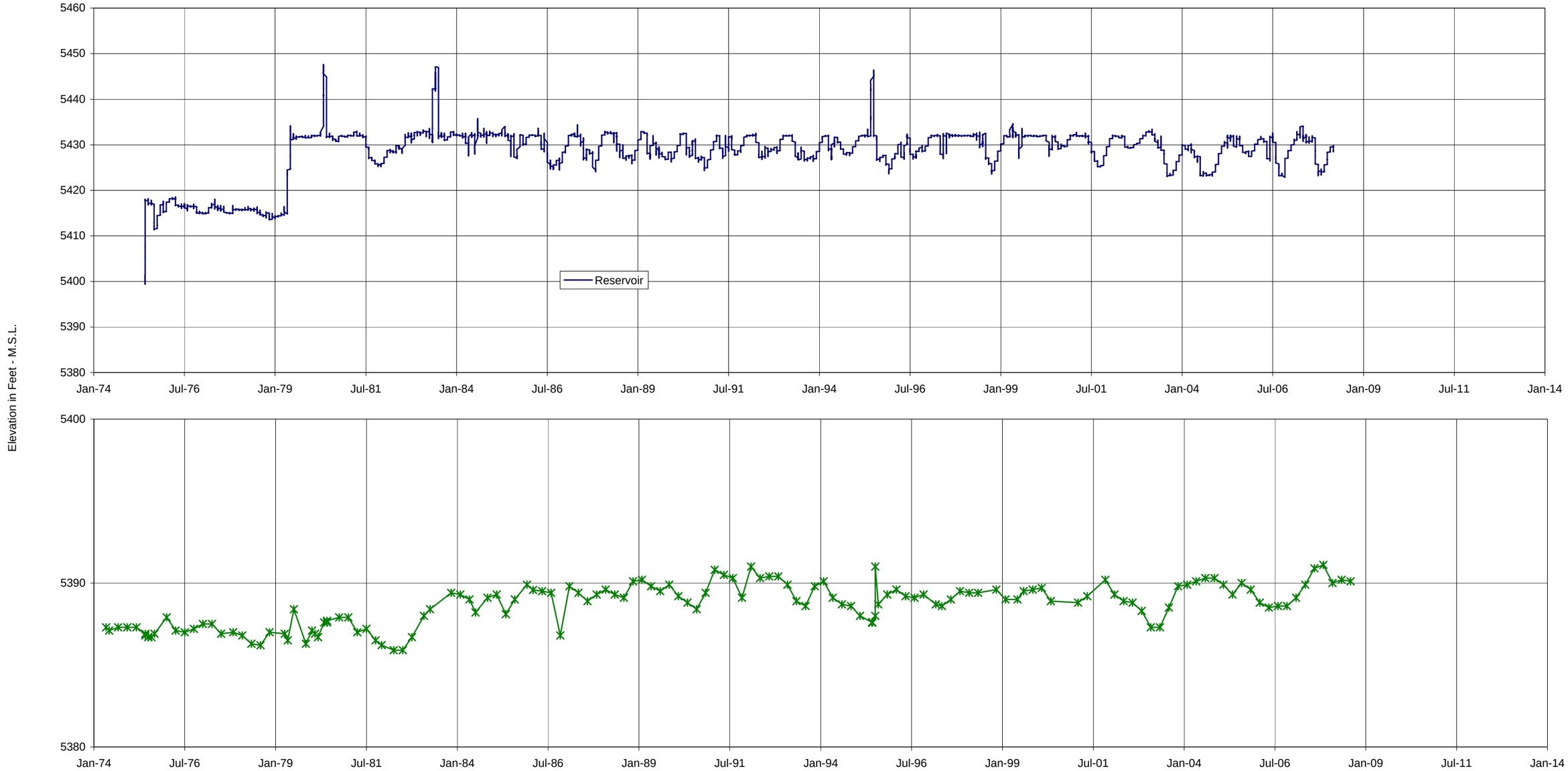


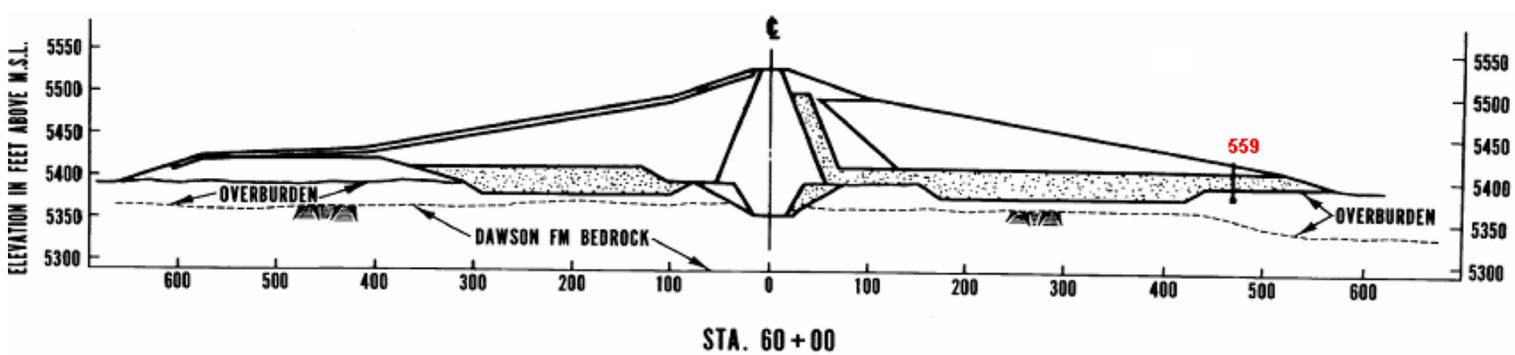
TYPE II
NO SCALE

LEGEND:

- □ Embankment Hydrostatic Pressure Cells
- △ Dawson Sandstone & Overburden (Type III)
- ○ Embankment-Foundation Pore Pressure (Type I)
- ● Embankment-Foundation Pore Pressure (Type II)
- ■ Terminal Wells/Boxes for Hydrostatic Pressure Cells

DESIGNED BY:	SOUTH PLATTE RIVER CHATFIELD LAKE, COLORADO EMBANKMENT PIEZOMETER LOCATION PLAN	
DRAWN BY:		
CHECKED BY:		
SUBMITTED BY: CHIEF SECTION		
RECOMMENDED: CHIEF DESIGN BRANCH	APPROVED: CHIEF ENGINEERING DIVISION	DATE:
APPROVED: COL. D. E., DISTRICT ENGINEER	SCALE: AS SHOWN	SPEC. NO. DACA45
	SHEET	DRAWING NUMBER

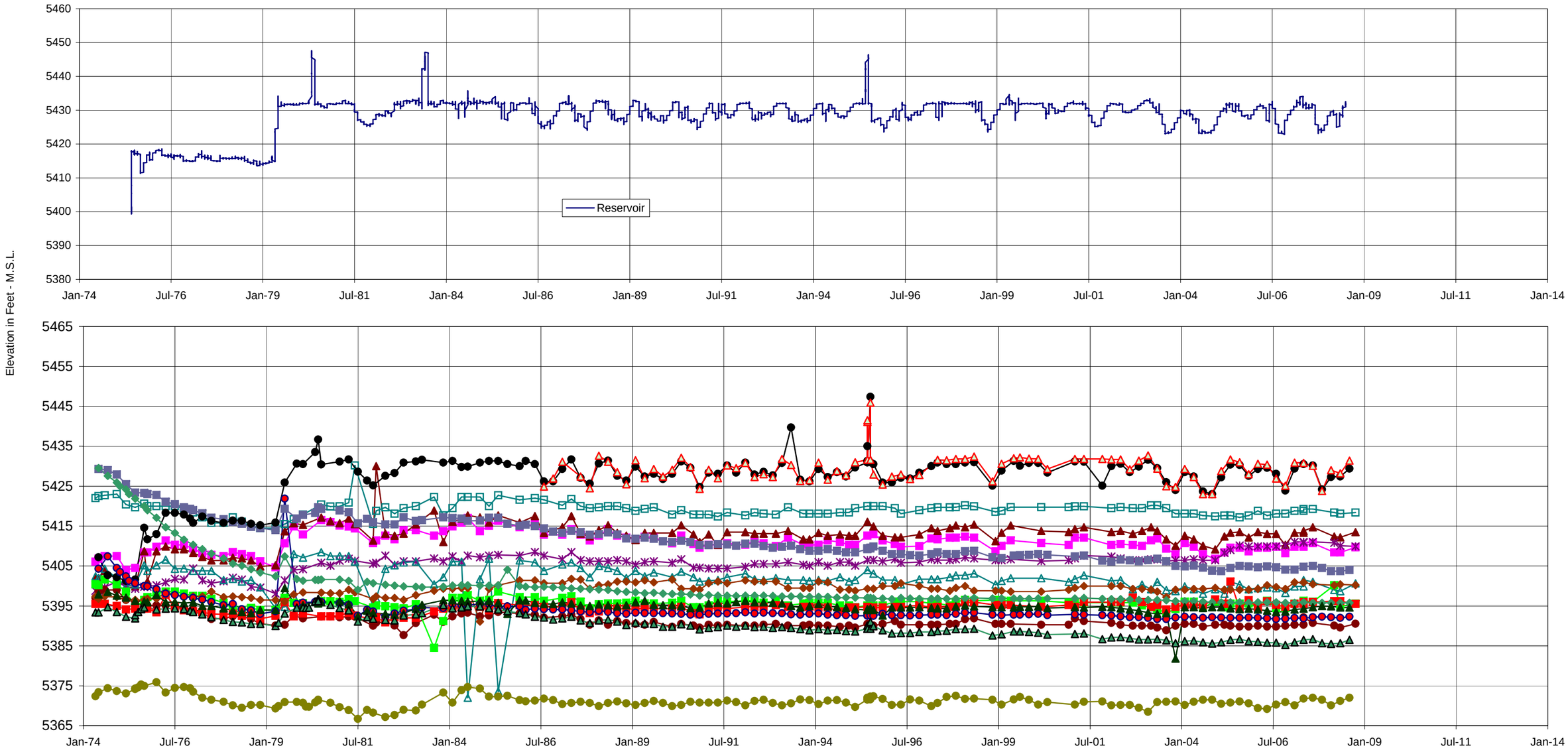


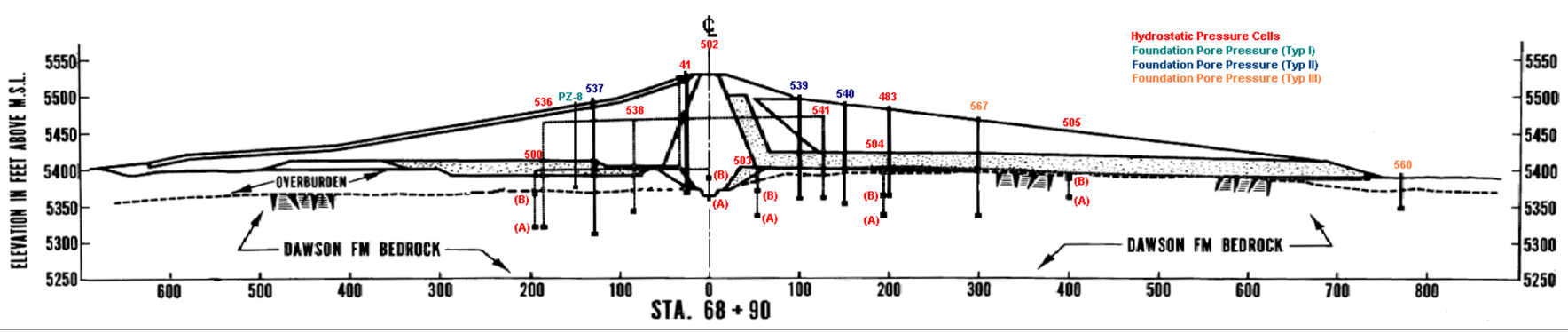


559

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 60+00

Re-Allocation Study Plate C-2

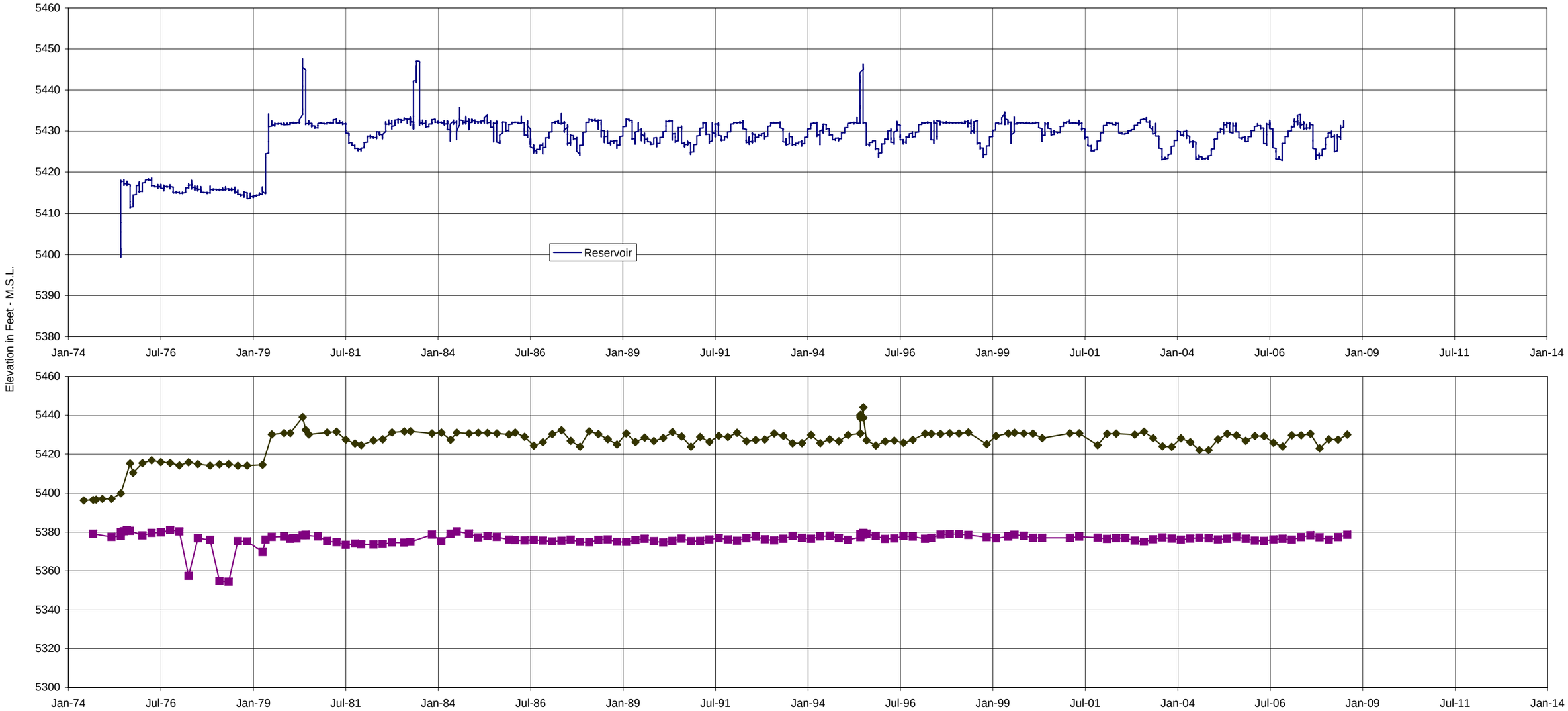


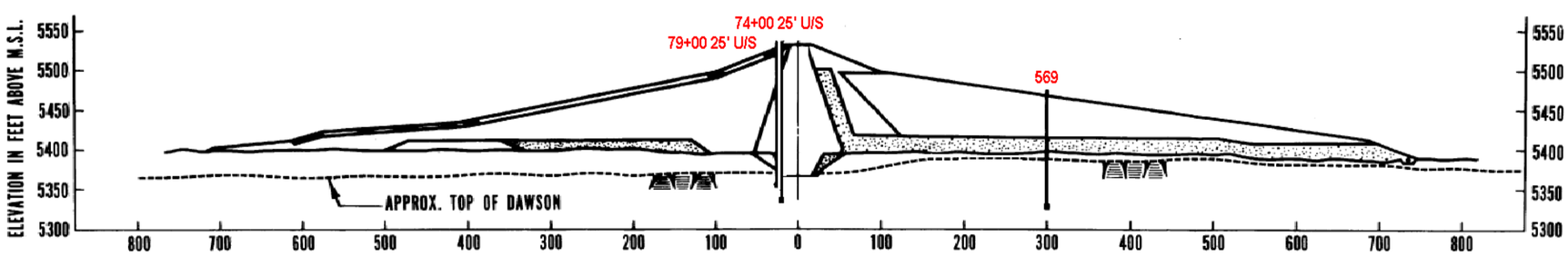


536 538A 502A 502B 541
504A 504B 505A 505B 537
41 539 540 483 567
560 PZ-8

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 68+90

Re-Allocation Study Plate C-3





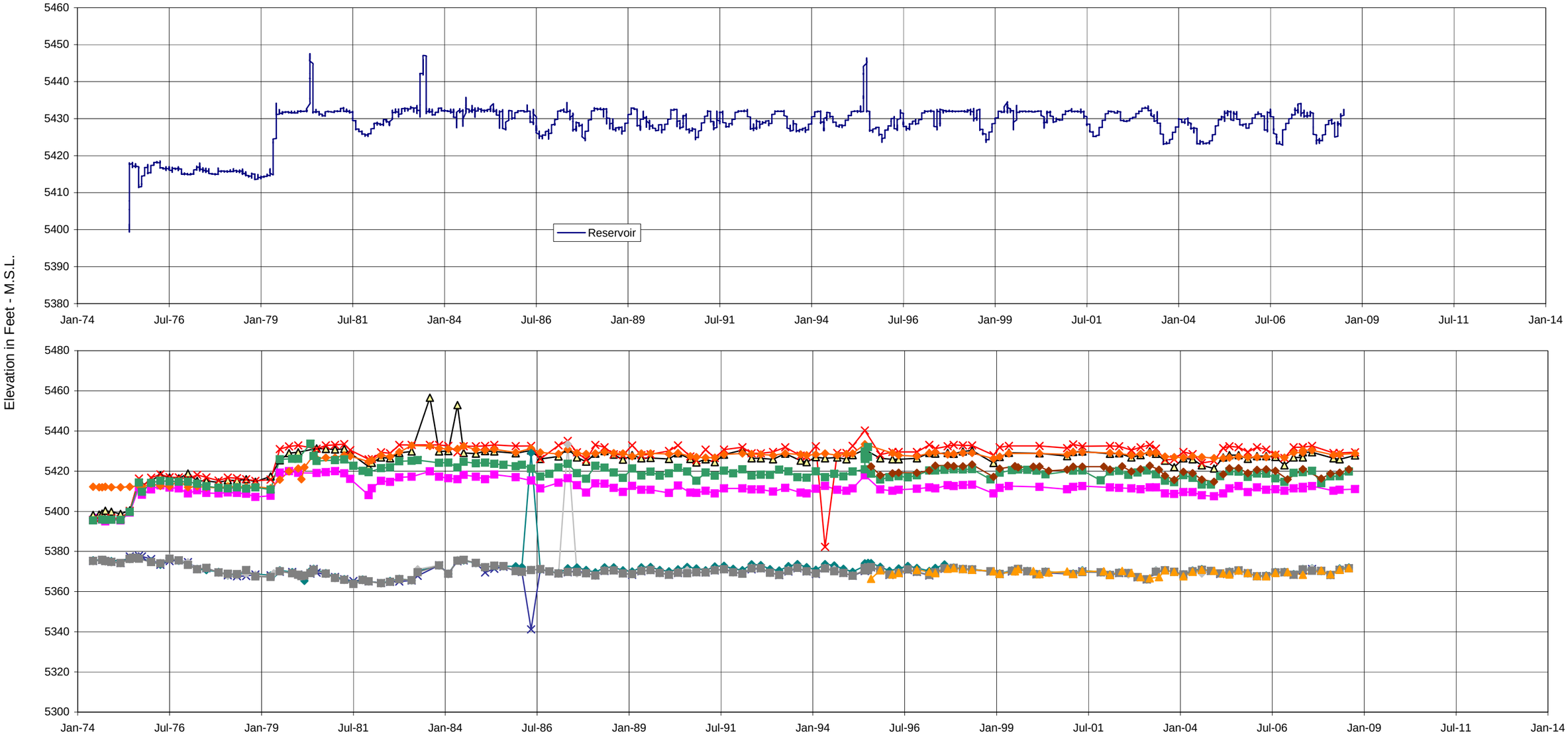
TYPICAL SECTION
STA. 74+00 TO STA. 79+00

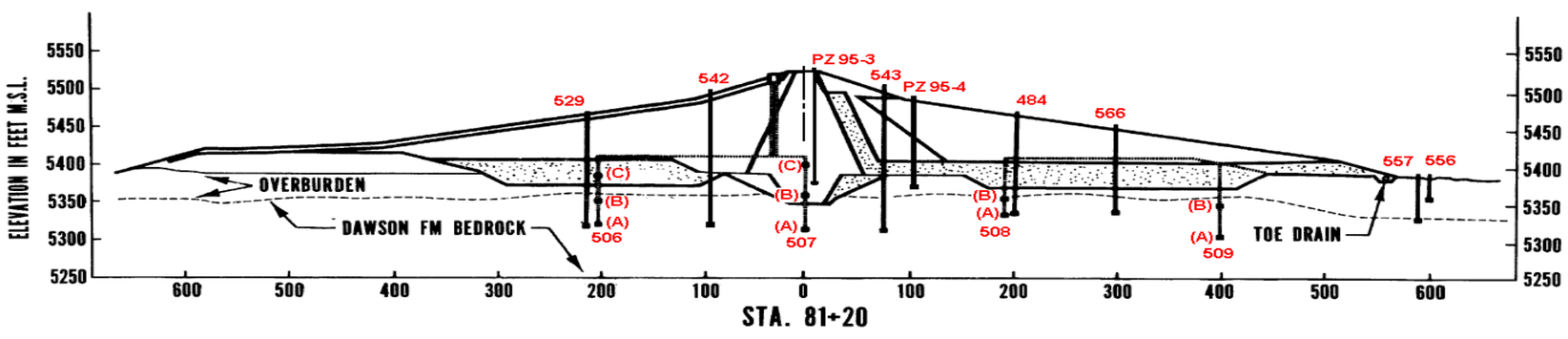
79+00/25US
569

NOTE: Piez 74+00 25' U/S was found plugged & was abandoned in July 1972

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 79+00

Re-Allocation Study Plate C-4

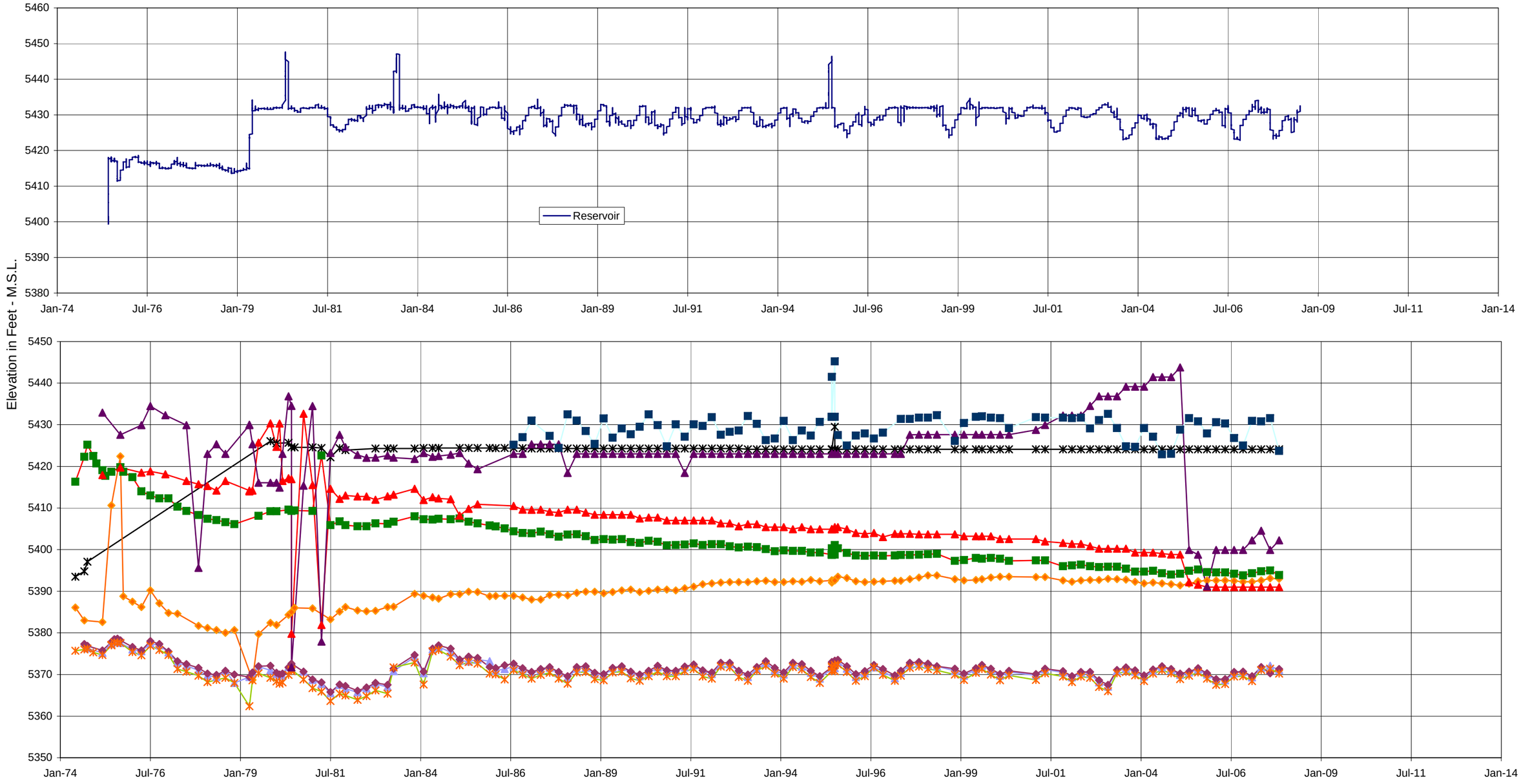


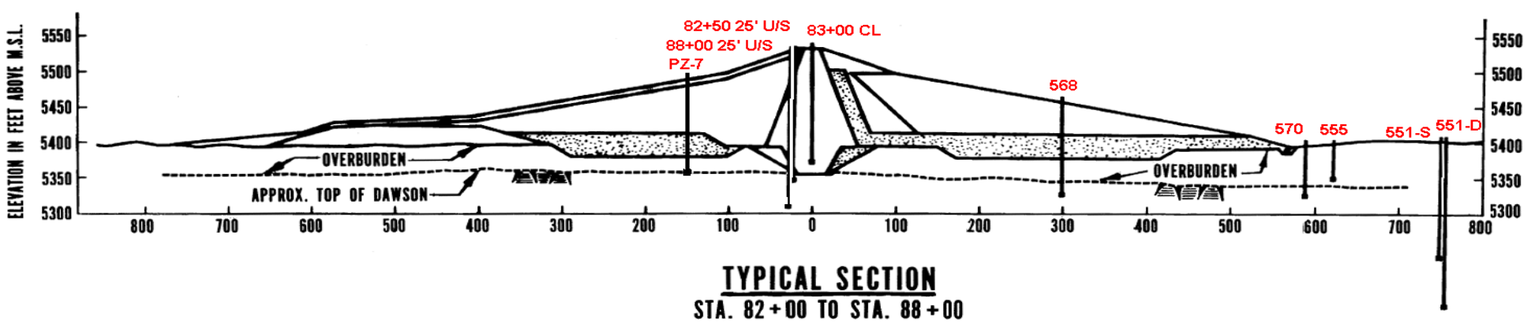


NOTE: Piez. 543 Reading discontinued Aug 1994 due to sounder cable broke and lodged in pipe.

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 81+20

Re-Allocation Study Plate C-5

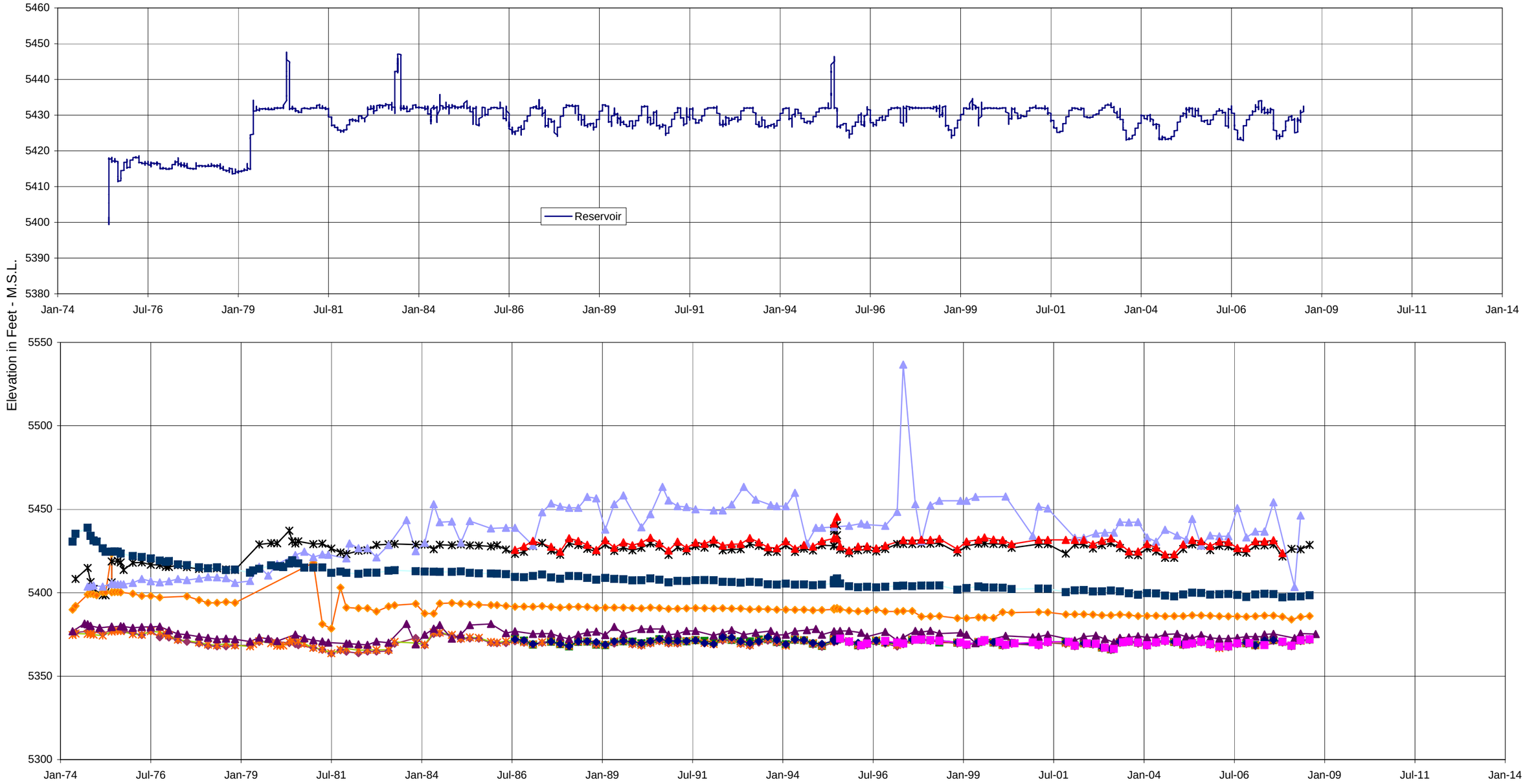


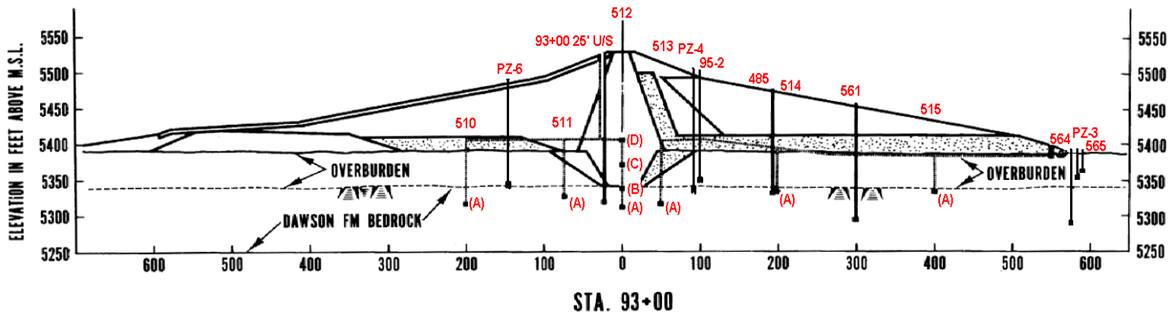


TYPICAL SECTION
STA. 82+00 TO STA. 88+00

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 82+00

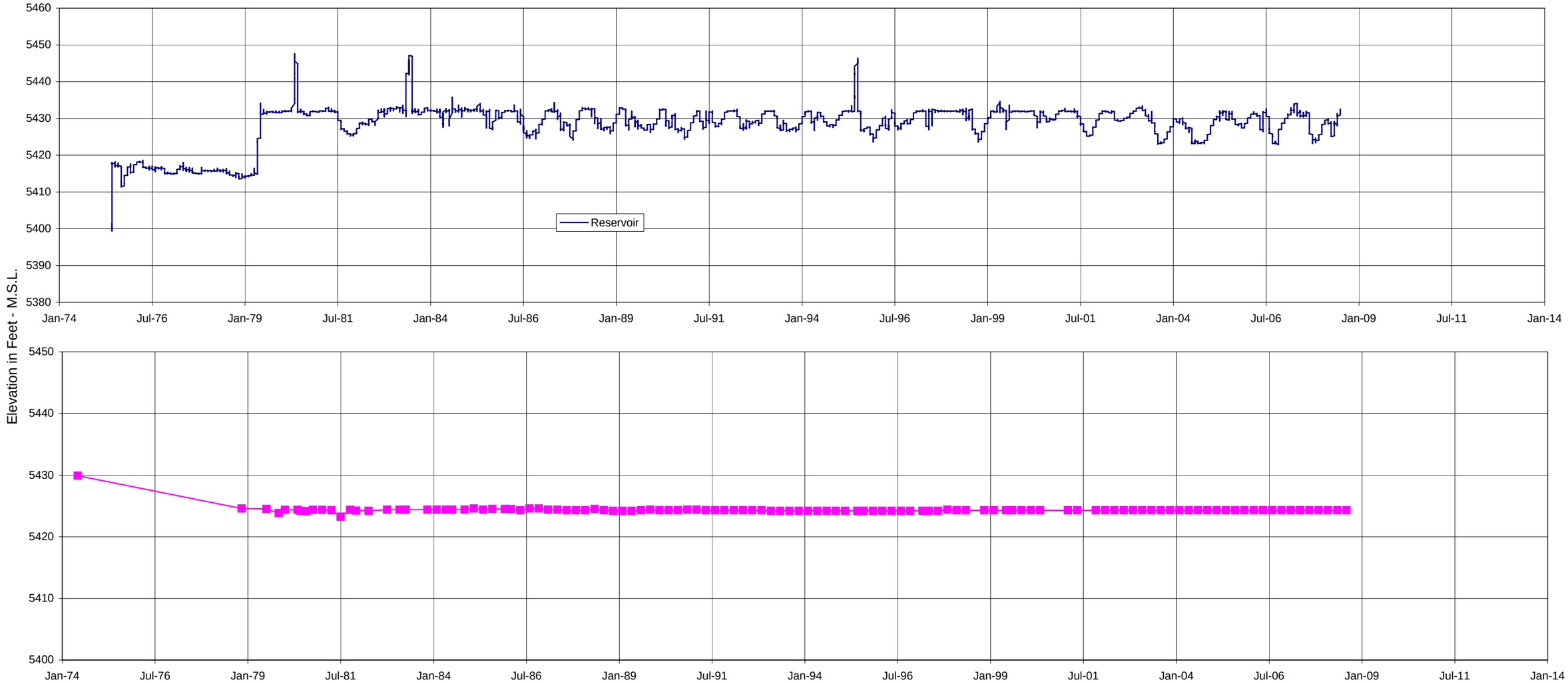
Re-Allocation Study Plate C-6

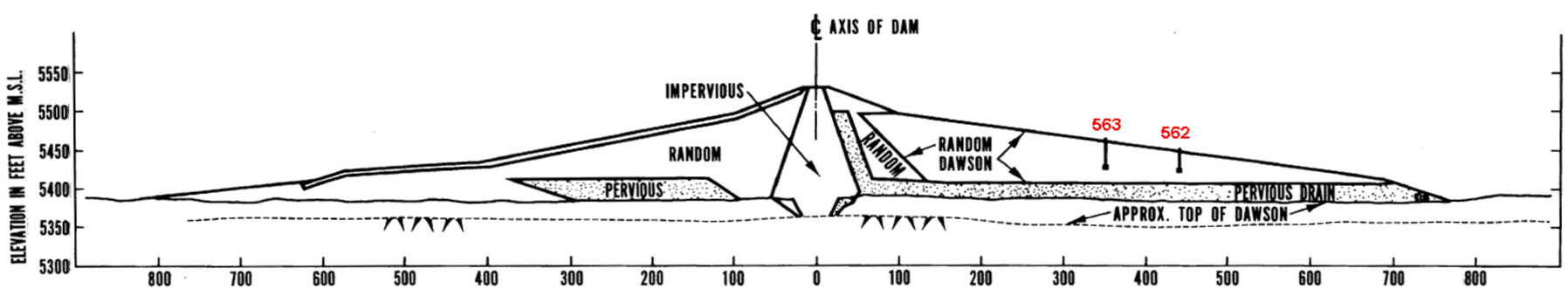




Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 93+00

Re-Allocation Study Plate C-7

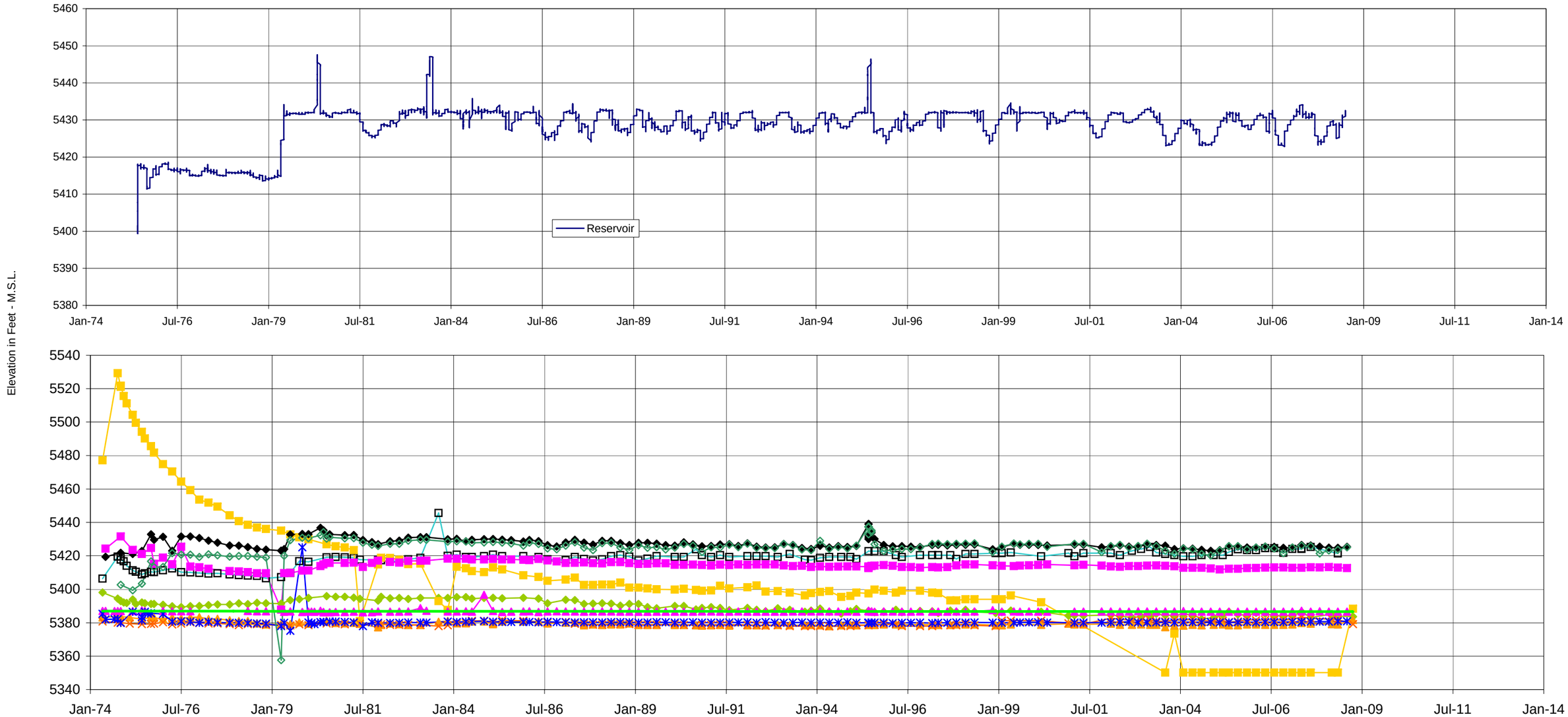


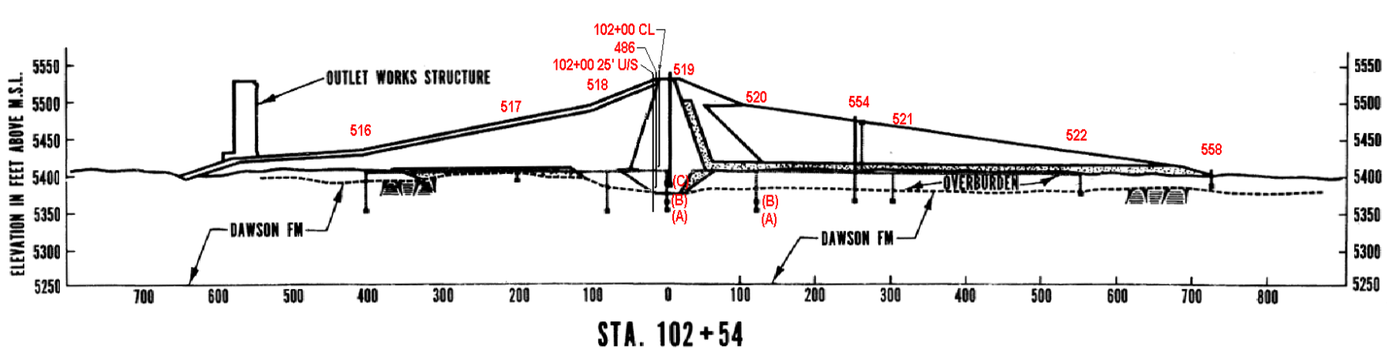


TYPICAL SECTION
STA. 99+00 TO STA. 102+00

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 99+00

Re-Allocation Study Plate C-8

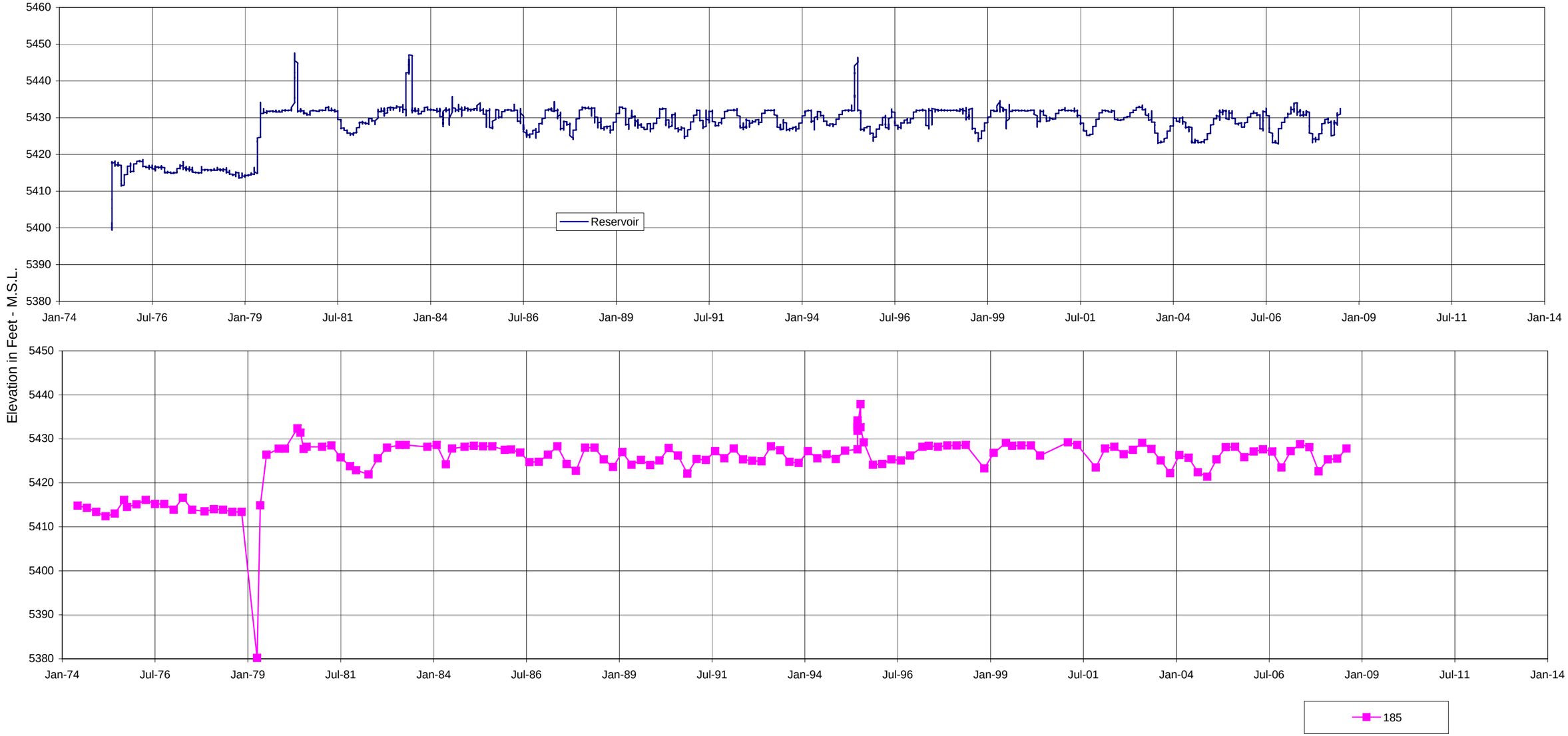


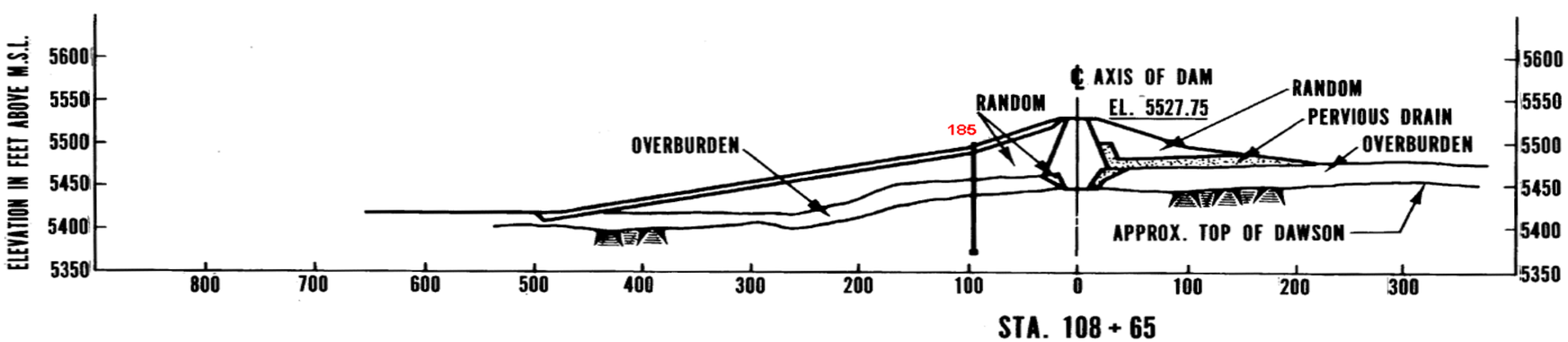


NOTE: Piez. 519A discontinued in May 1985 due to erratic behavior.
Piez. 519B discontinued in Aug 1995 due to difficulty in obtaining readings.
Piez 516 discontinued in Aug 1995 due to erratic behavior.

Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 102+54

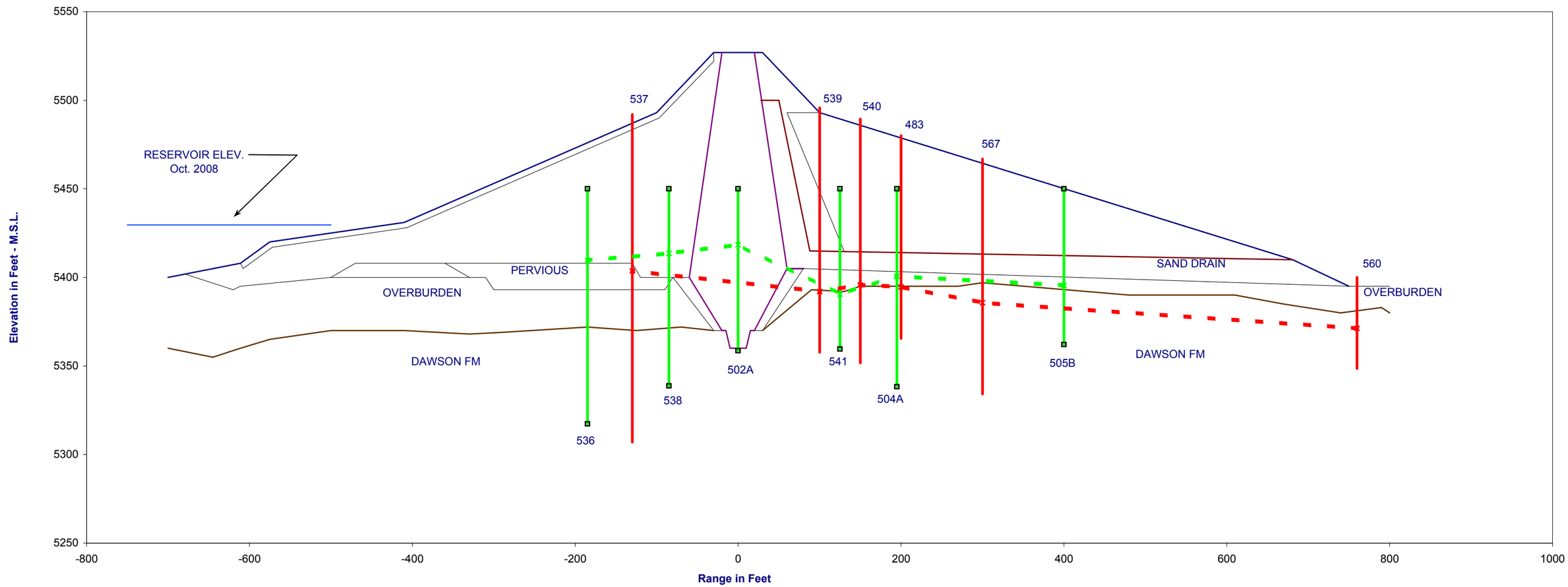
Re-Allocation Study Plate C-9





Chatfield Dam and Lake, Colorado
Main Embankment & Foundation Piezmeter Observations
Station 108+65

Re-Allocation Study Plate C-10



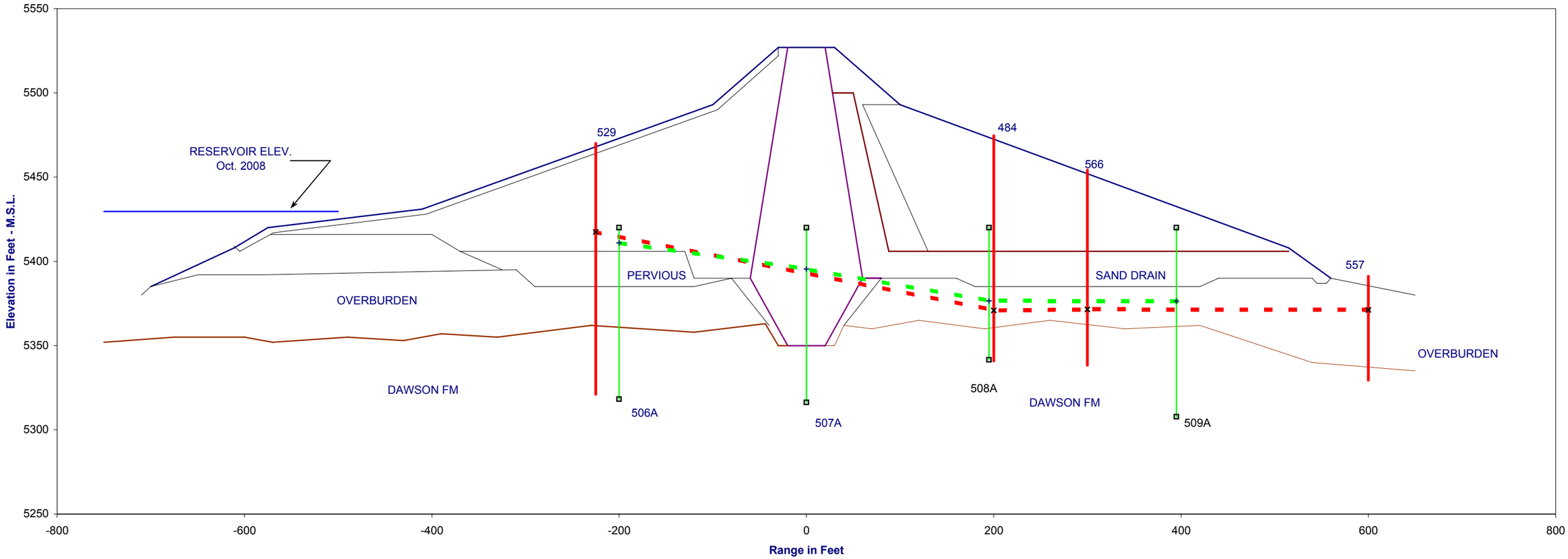
Embankment Station 68+80 to 68+90

Open Tube - May 2008 Data Res. El.(5431.15)

Pressure Cell - Oct 2008 Data Res. El.(5429.61)

Chatfield Dam and Lake, CO
Foundation Piezometer Observations
Station 68+80 to 68+90

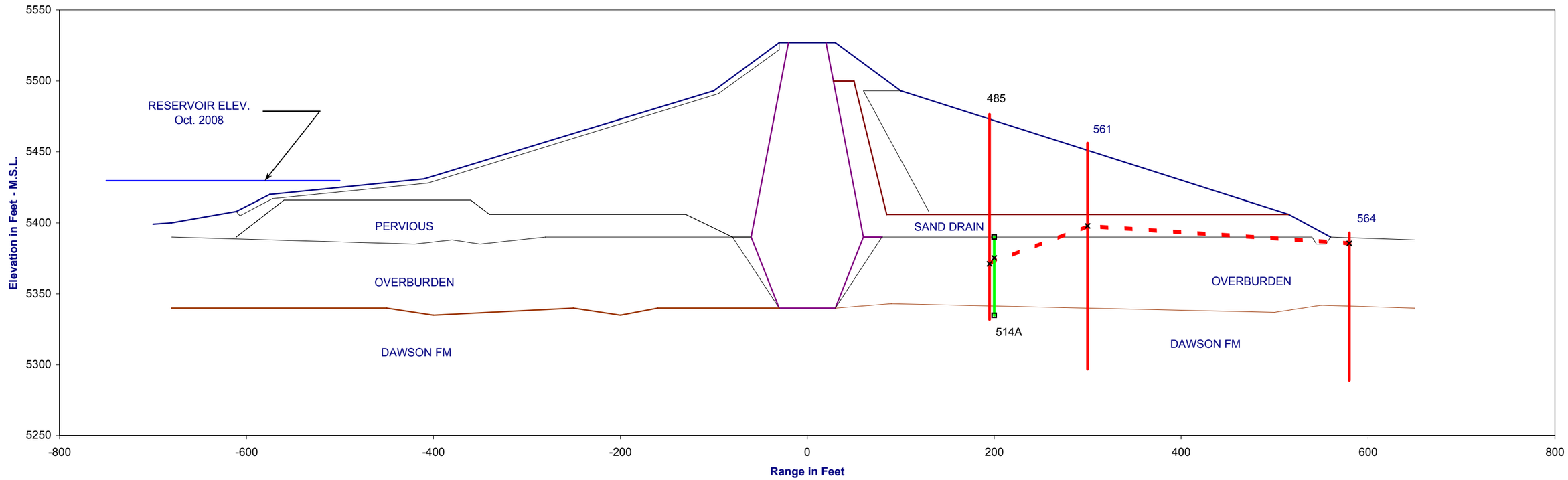
RE-ALLOCATION STUDY PLATE C-11



Embankment Station 81+10 to 81+20
Open Tube - May 2008 Data Res. El. (5431.15)
Pressure Cell - Oct 2008 Data Res. El.(5429.61)

Chatfield Dam and Lake, CO
Foundation Piezometer Observations
Station 81+10 to 81+20

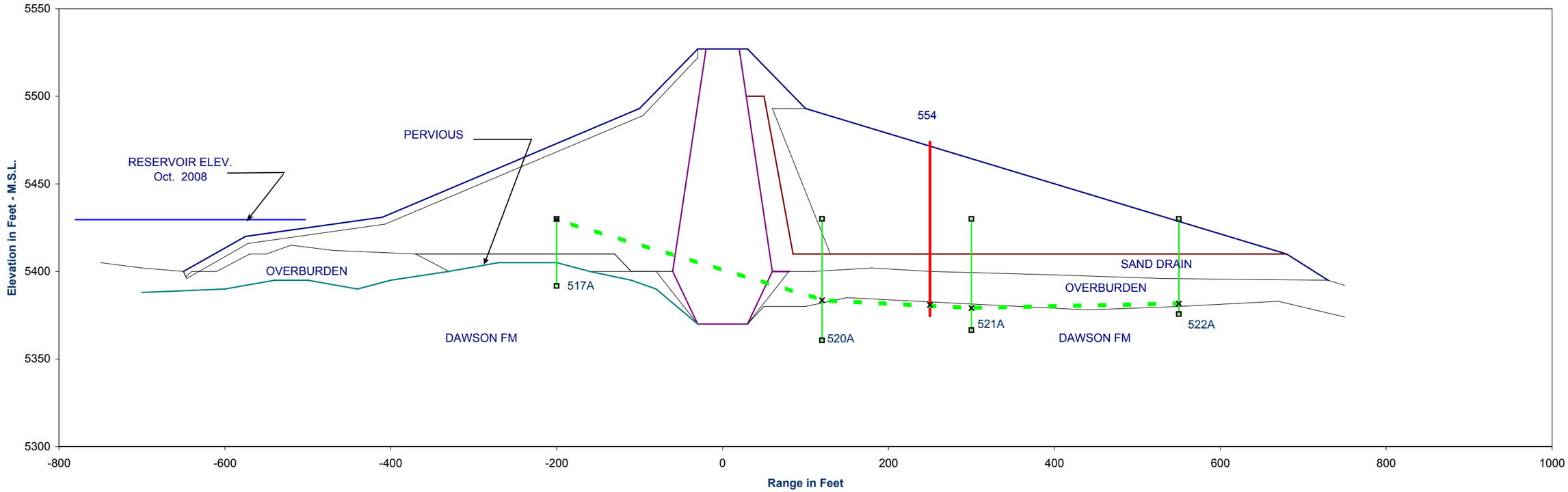
RE-ALLOCATION STUDY PLATE C-12



Embankment Station 92+90-93+02
Open Tube - May 2008 Data Res. El. (5431.15)
Pressure Cell - Oct 2008 Data Res. El.(5429.61)

Chatfield Dam and Lake, CO
Foundation Piezometer Observations
Station 93+00

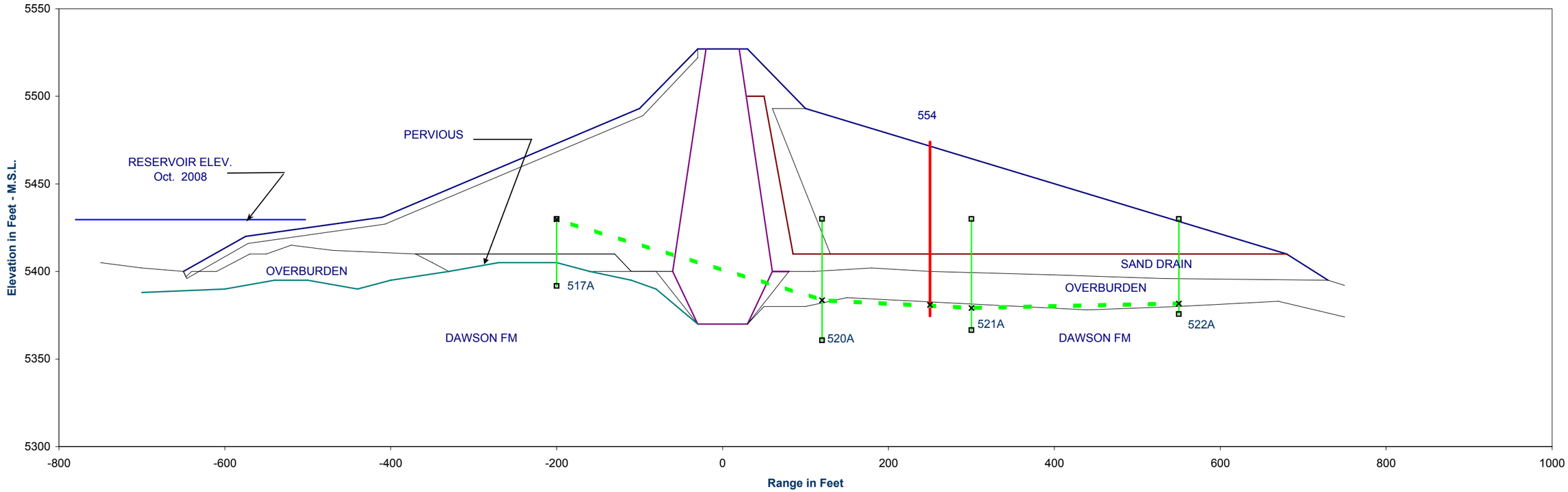
RE-ALLOCATION STUDY PLATE C-13



Embankment Station 101+35-102+00
Open Tube - May 2008 Data Res. El. (5431.15)
Pressure Cell - Oct 2008 Data Res. El.(5429.61)

Chatfield Dam and Lake, CO
Foundation Piezometer Observations
Station 101+35 to 102+00

RE-ALLOCATION STUDY PLATE C-14



Embankment Station 101+35-102+00
Open Tube - May 2008 Data Res. El. (5431.15)
Pressure Cell - Oct 2008 Data Res. El.(5429.61)

Chatfield Dam and Lake, CO
Foundation Piezometer Observations
Station 101+35 to 102+00

RE-ALLOCATION STUDY PLATE C-14

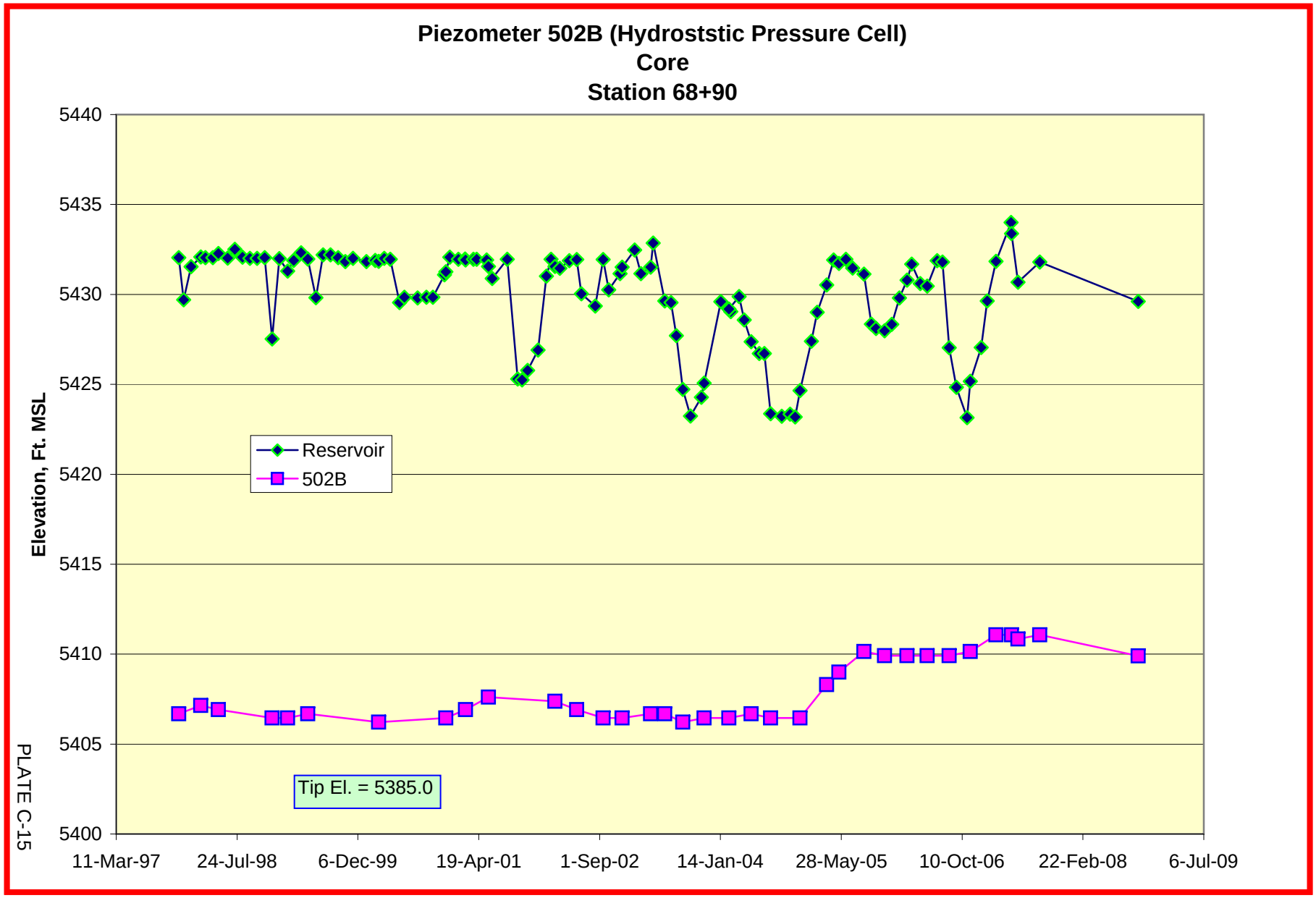

Piezometer 502B (Hydroststic Pressure Cell)
Core
Station 68+90
Elevation, Ft. MSL
5440
5435
5430
5425
5420
5415
5410
5405
5400
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09
Reservoir
502B
Tip El. = 5385.0

PLATE C-15

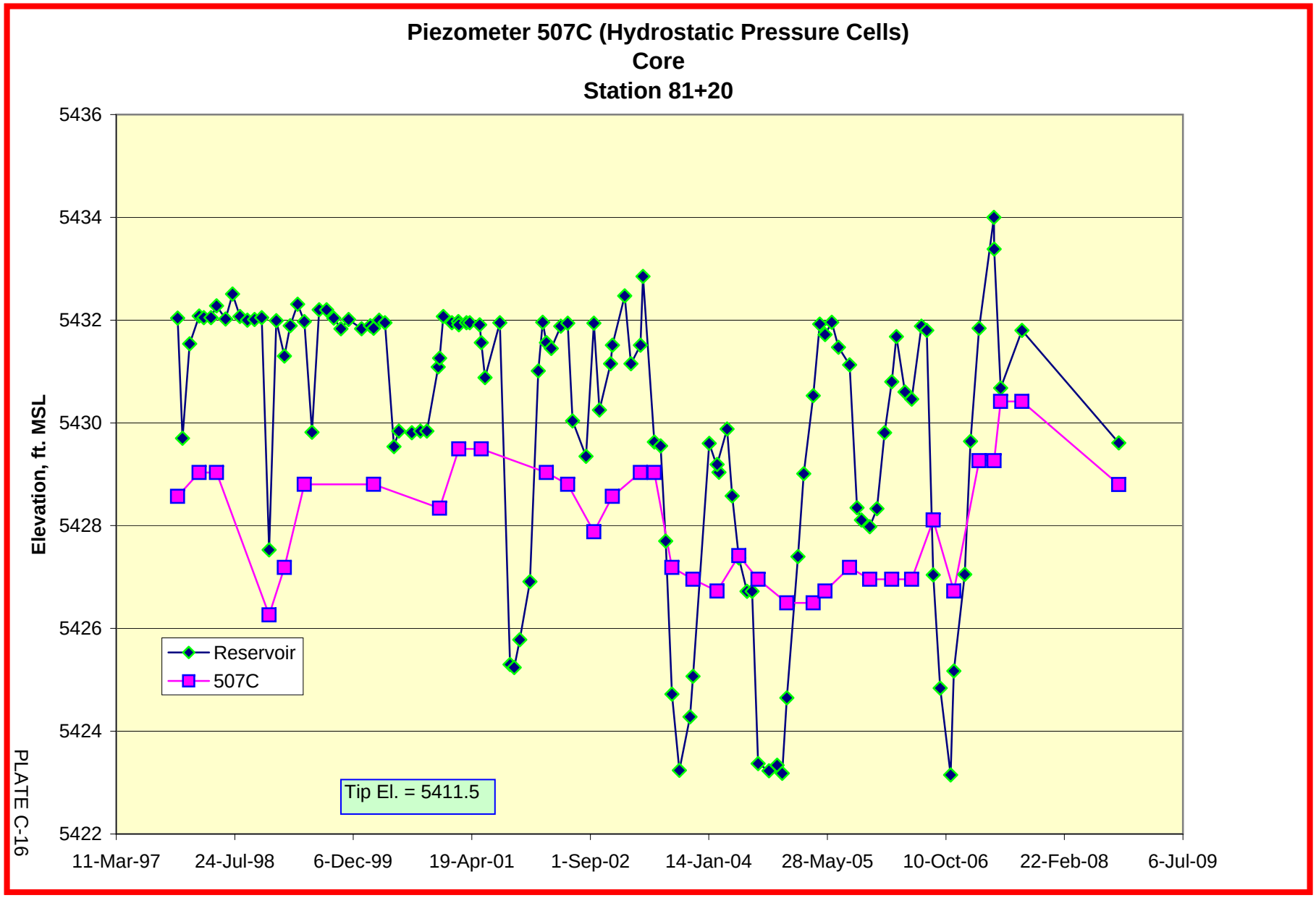
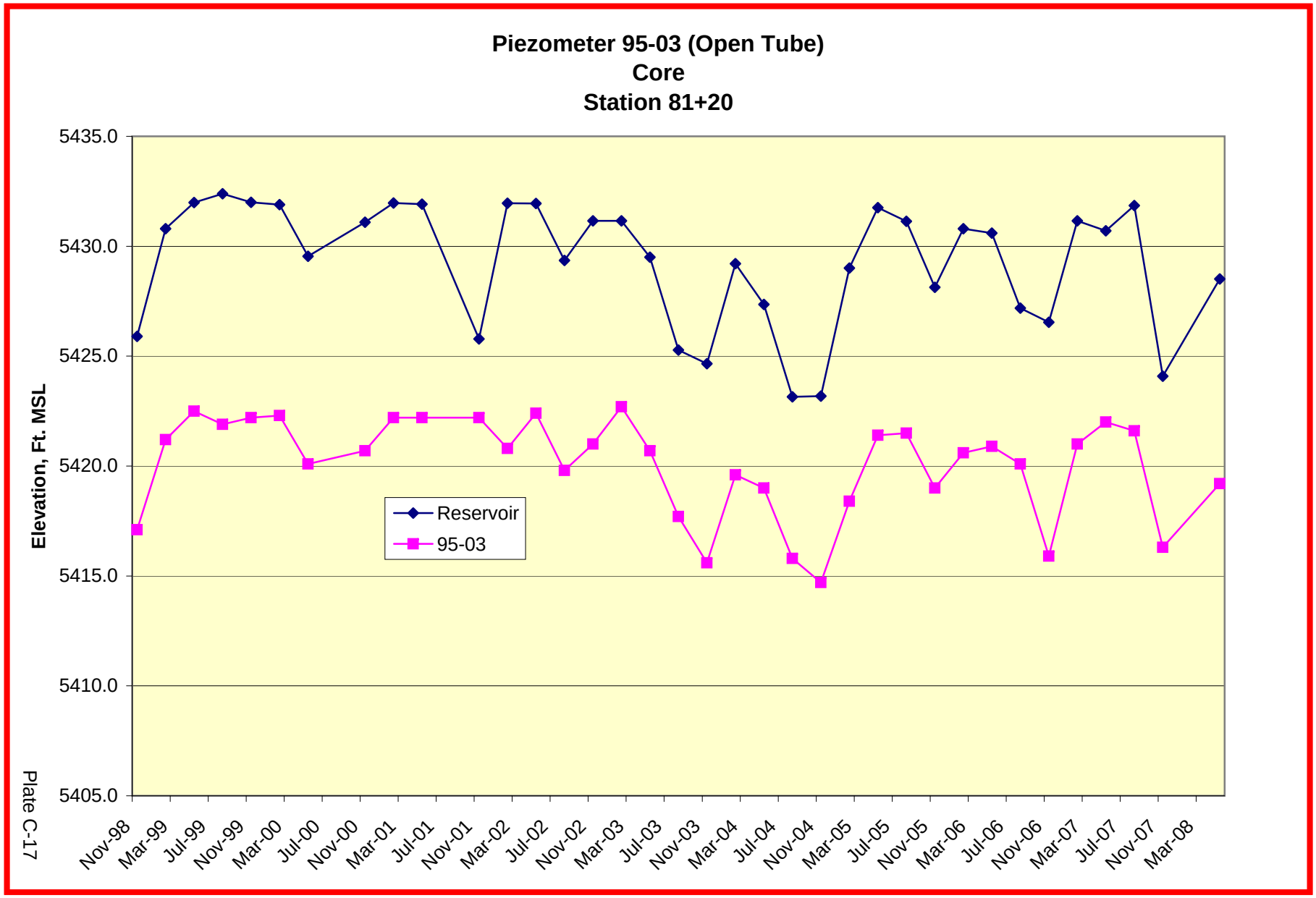
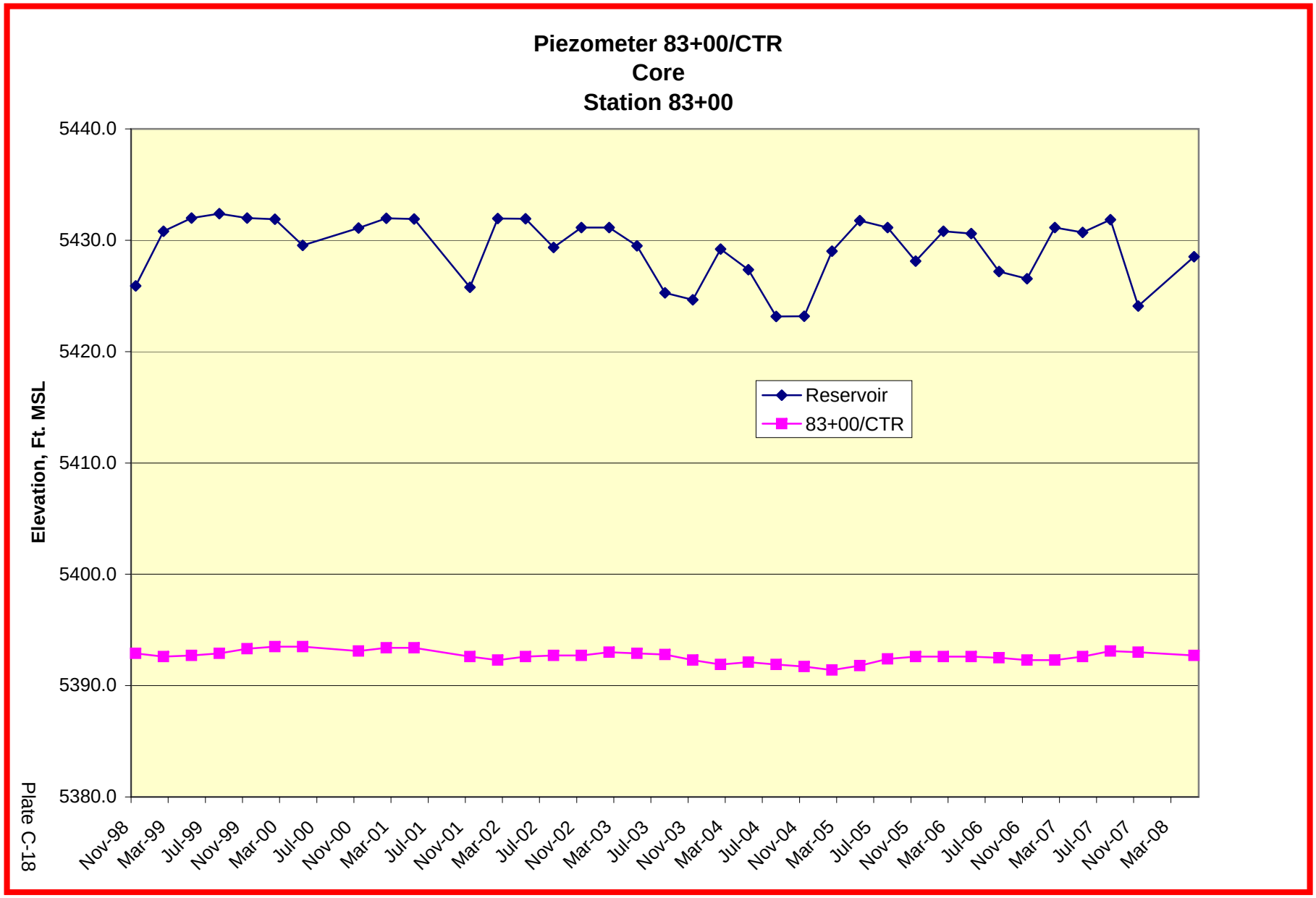

Piezometer 507C (Hydrostatic Pressure Cells)
Core
Station 81+20
Elevation, ft. MSL
5436
5434
5432
5430
5428
5426
5424
5422
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09
Reservoir
507C
Tip El. = 5411.5

PLATE C-16


Piezometer 95-03 (Open Tube)
Core
Station 81+20
Elevation, Ft. MSL
5435.0
5430.0
5425.0
5420.0
5415.0
5410.0
5405.0
Reservoir
95-03
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 83+00/CTR
Core
Station 83+00
Elevation, Ft. MSL
5440.0
5430.0
5420.0
5410.0
5400.0
5390.0
5380.0
Reservoir
83+00/CTR
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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Jul-05
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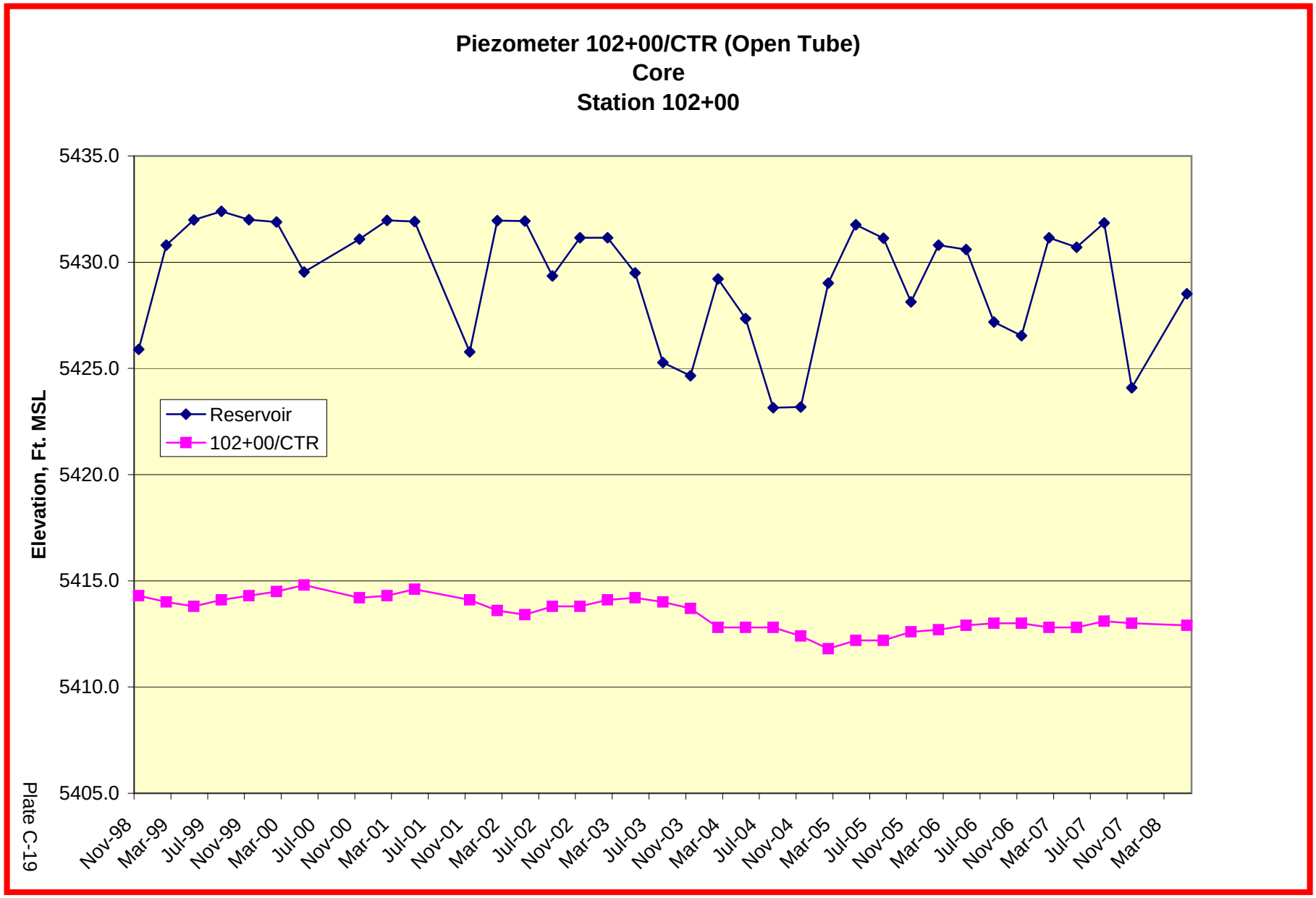
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 102+00/CTR (Open Tube)
Core
Station 102+00
Elevation, Ft. MSL
5435.0
5430.0
5425.0
5420.0
5415.0
5410.0
5405.0
Reservoir
102+00/CTR
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08

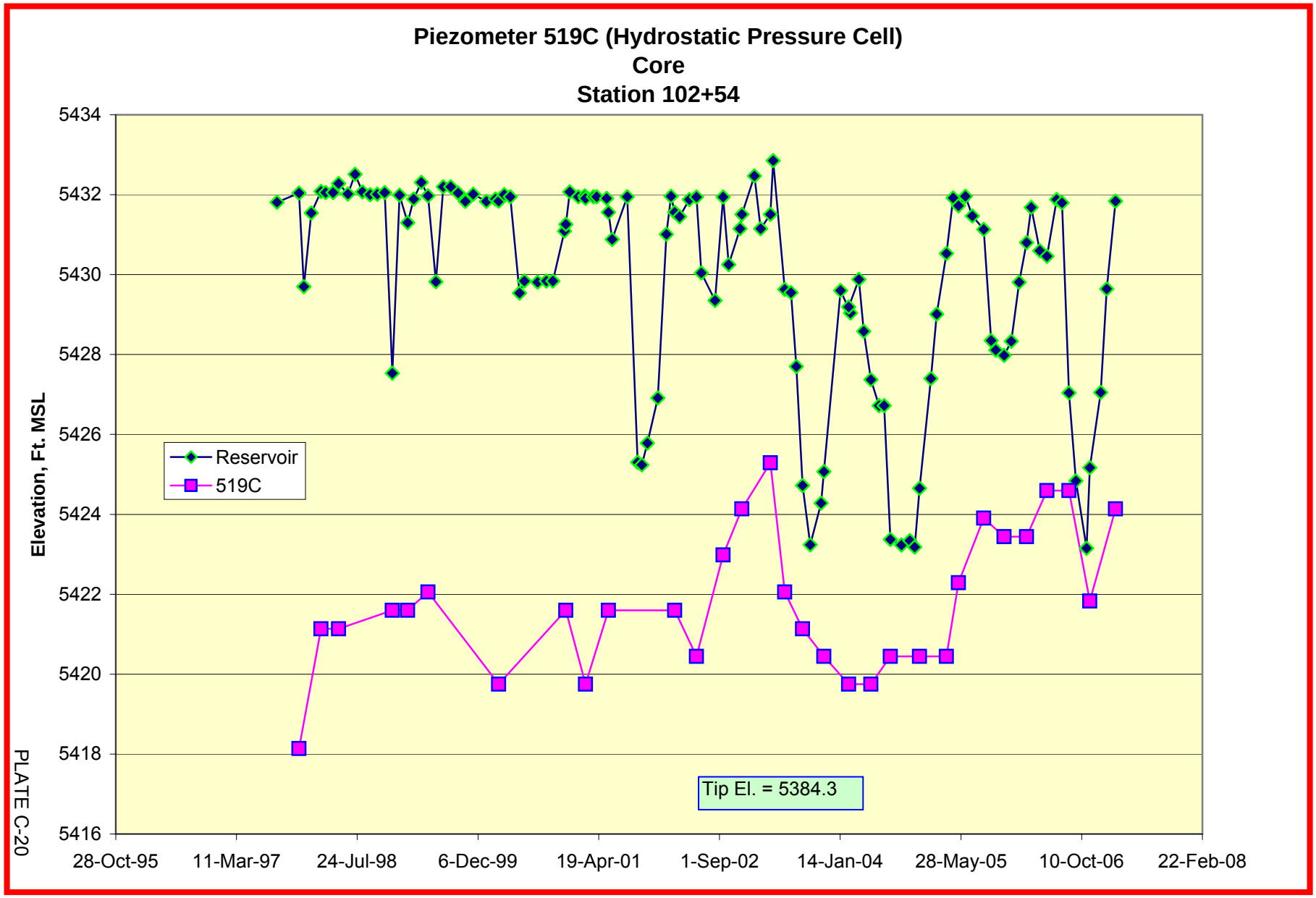

Piezometer 519C (Hydrostatic Pressure Cell)
Core
Station 102+54
Elevation, Ft. MSL
5434
5432
5430
5428
5426
5424
5422
5420
5418
5416
28-Oct-95
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
Reservoir
519C
Tip El. = 5384.3

PLATE C-20

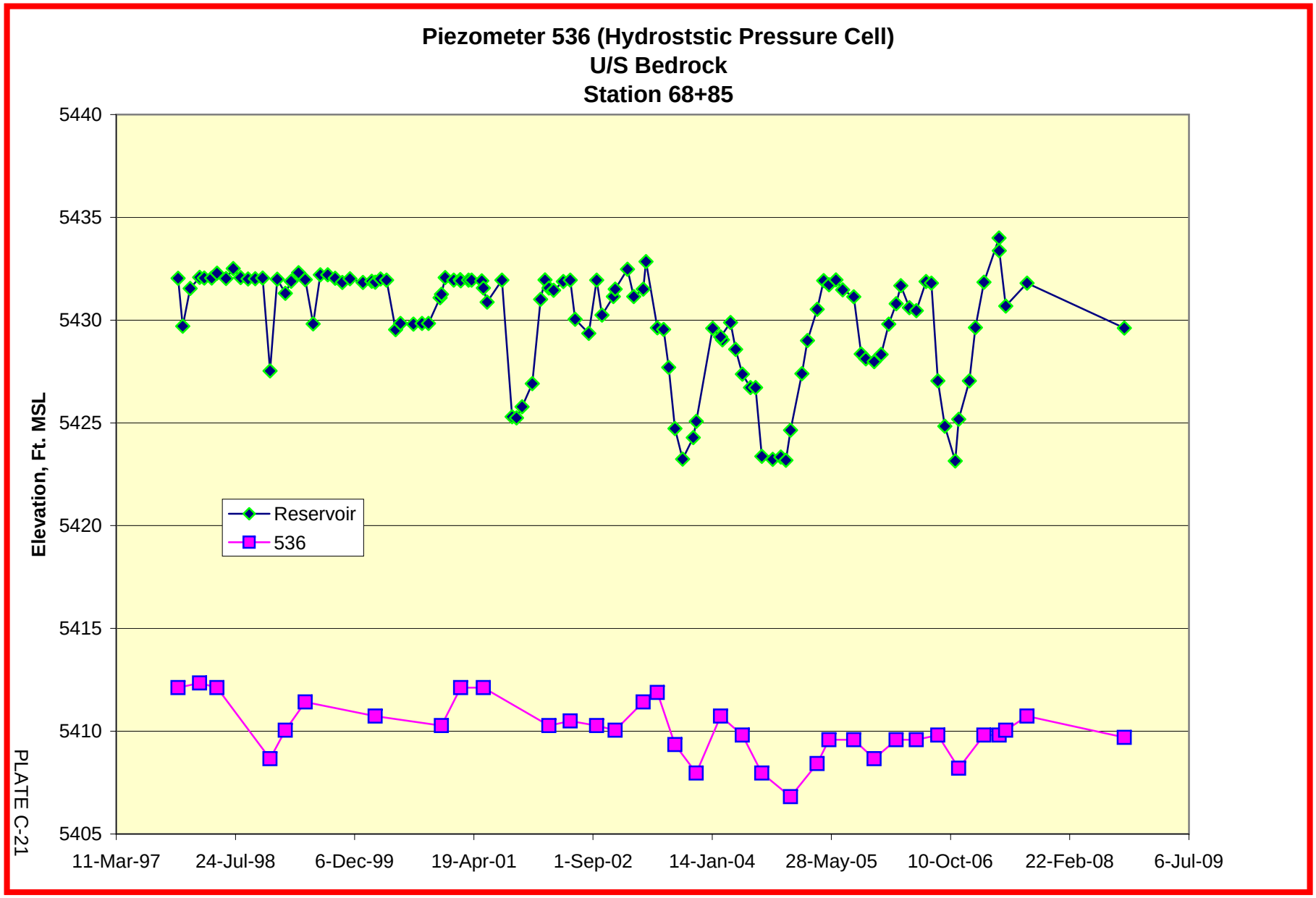
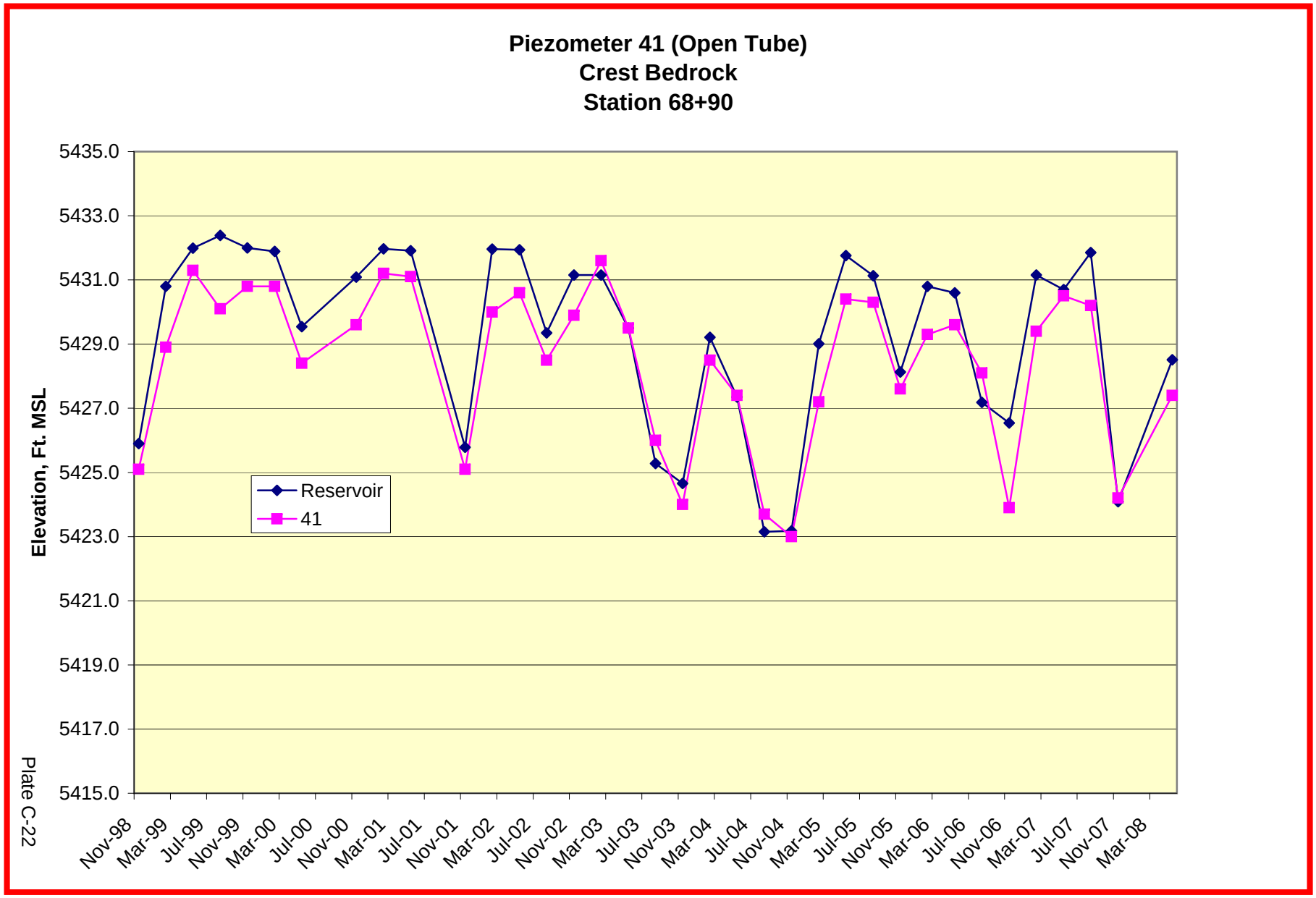

Piezometer 536 (Hydroststic Pressure Cell)
U/S Bedrock
Station 68+85
Elevation, Ft. MSL
5440
5435
5430
5425
5420
5415
5410
5405
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09
Reservoir
536

PLATE C-21


Piezometer 41 (Open Tube)
Crest Bedrock
Station 68+90
Elevation, Ft. MSL
5435.0
5433.0
5431.0
5429.0
5427.0
5425.0
5423.0
5421.0
5419.0
5417.0
5415.0
Reservoir
41
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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Jul-05
Nov-05
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08

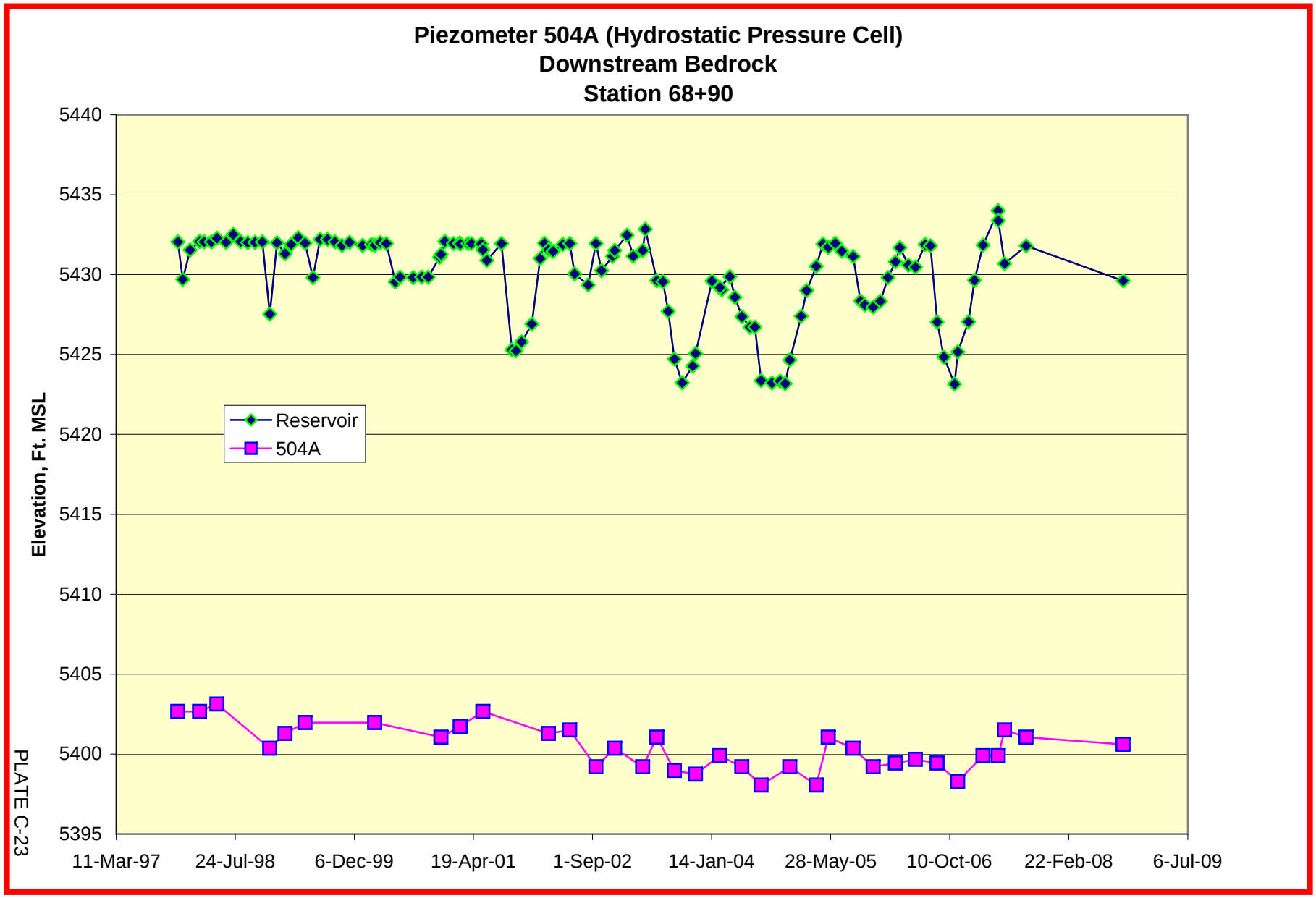

Piezometer 504A (Hydrostatic Pressure Cell)
Downstream Bedrock
Station 68+90
Elevation, Ft. MSL
5440
5435
5430
5425
5420
5415
5410
5405
5400
5395
Reservoir
504A
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09

PLATE C-23

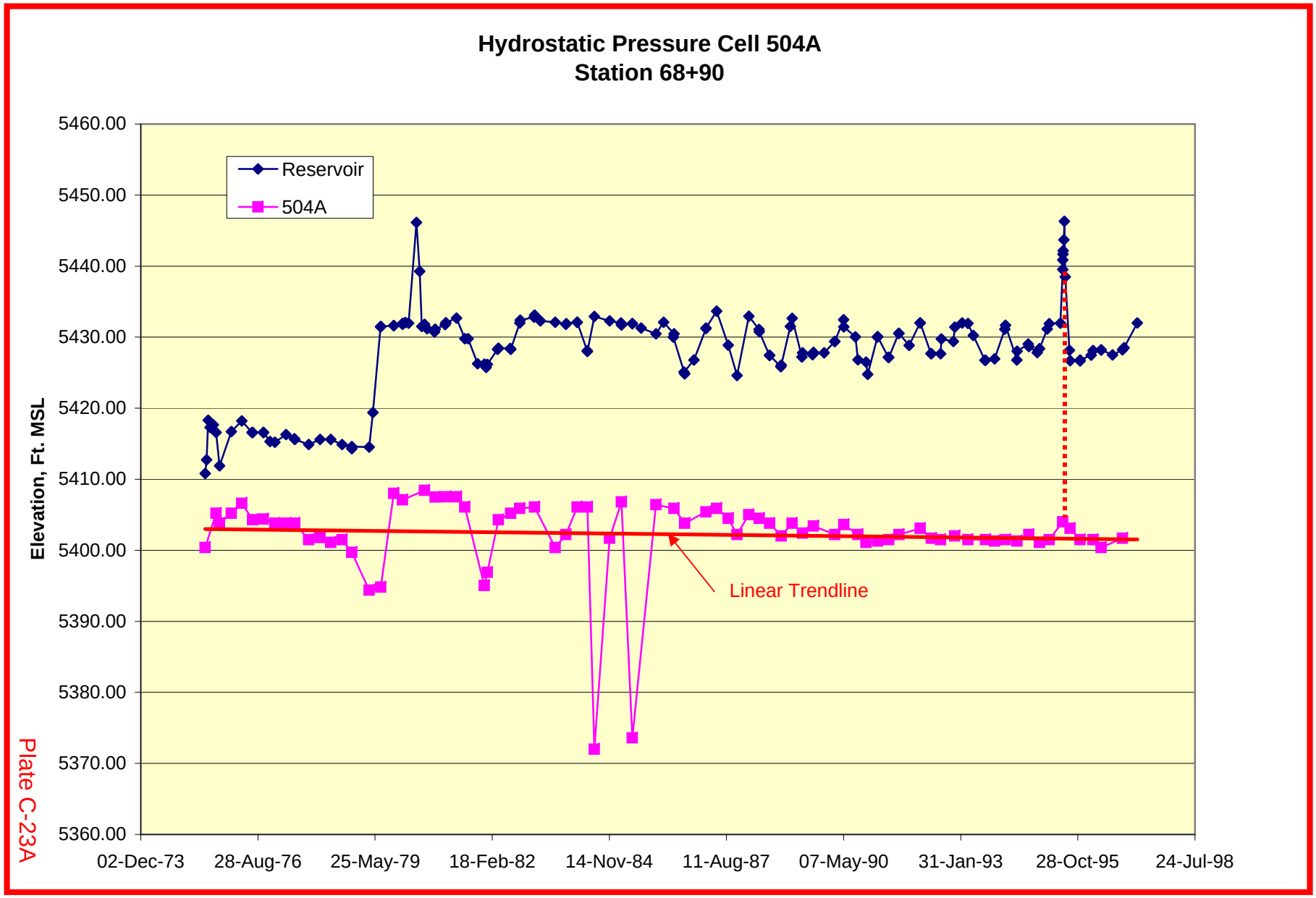

Hydrostatic Pressure Cell 504A
Station 68+90
Reservoir
504A
Linear Trendline
Elevation, Ft. MSL
5460.00
5450.00
5440.00
5430.00
5420.00
5410.00
5400.00
5390.00
5380.00
5370.00
5360.00
02-Dec-73
28-Aug-76
25-May-79
18-Feb-82
14-Nov-84
11-Aug-87
07-May-90
31-Jan-93
28-Oct-95
24-Jul-98

Plate C-23A

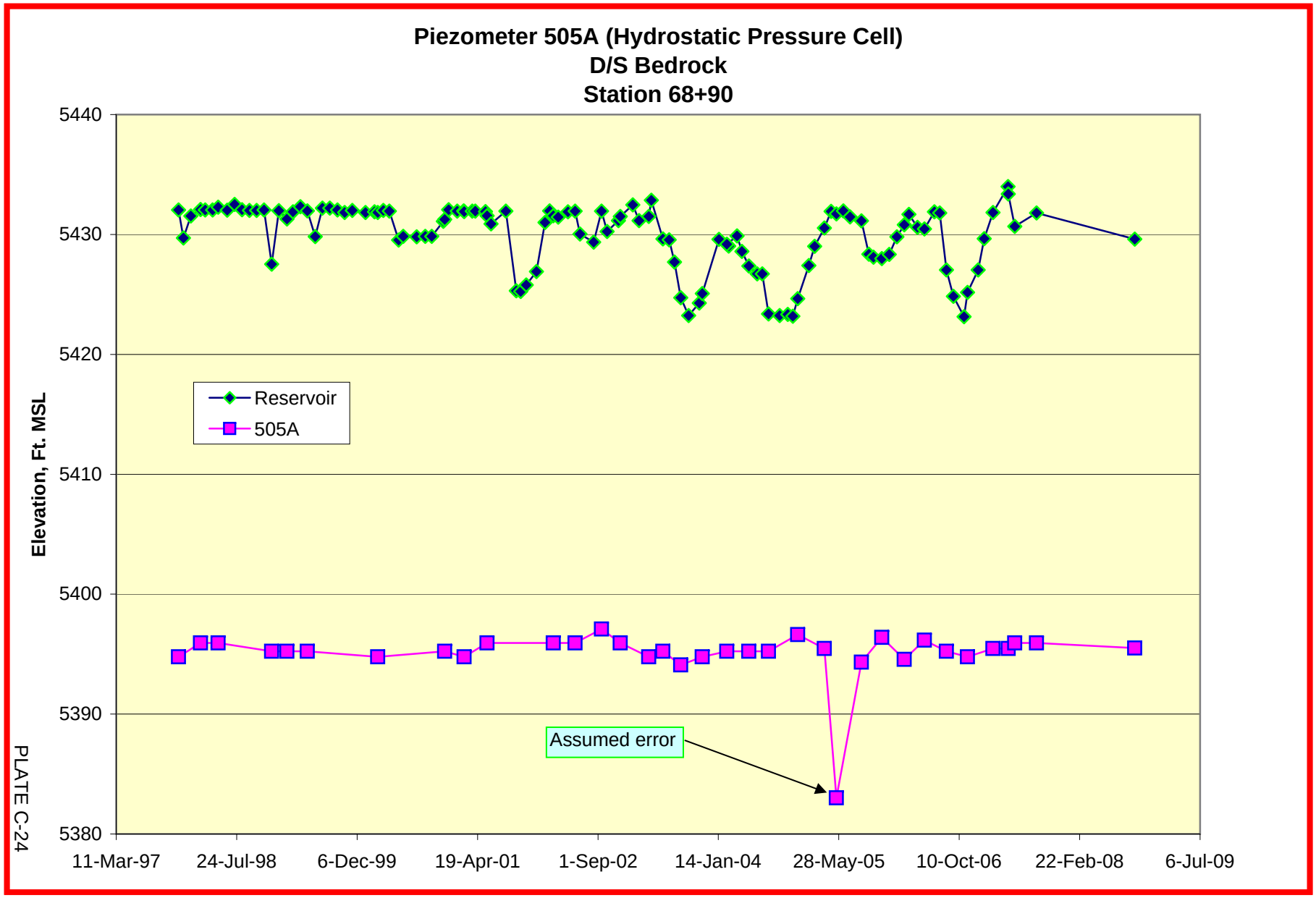
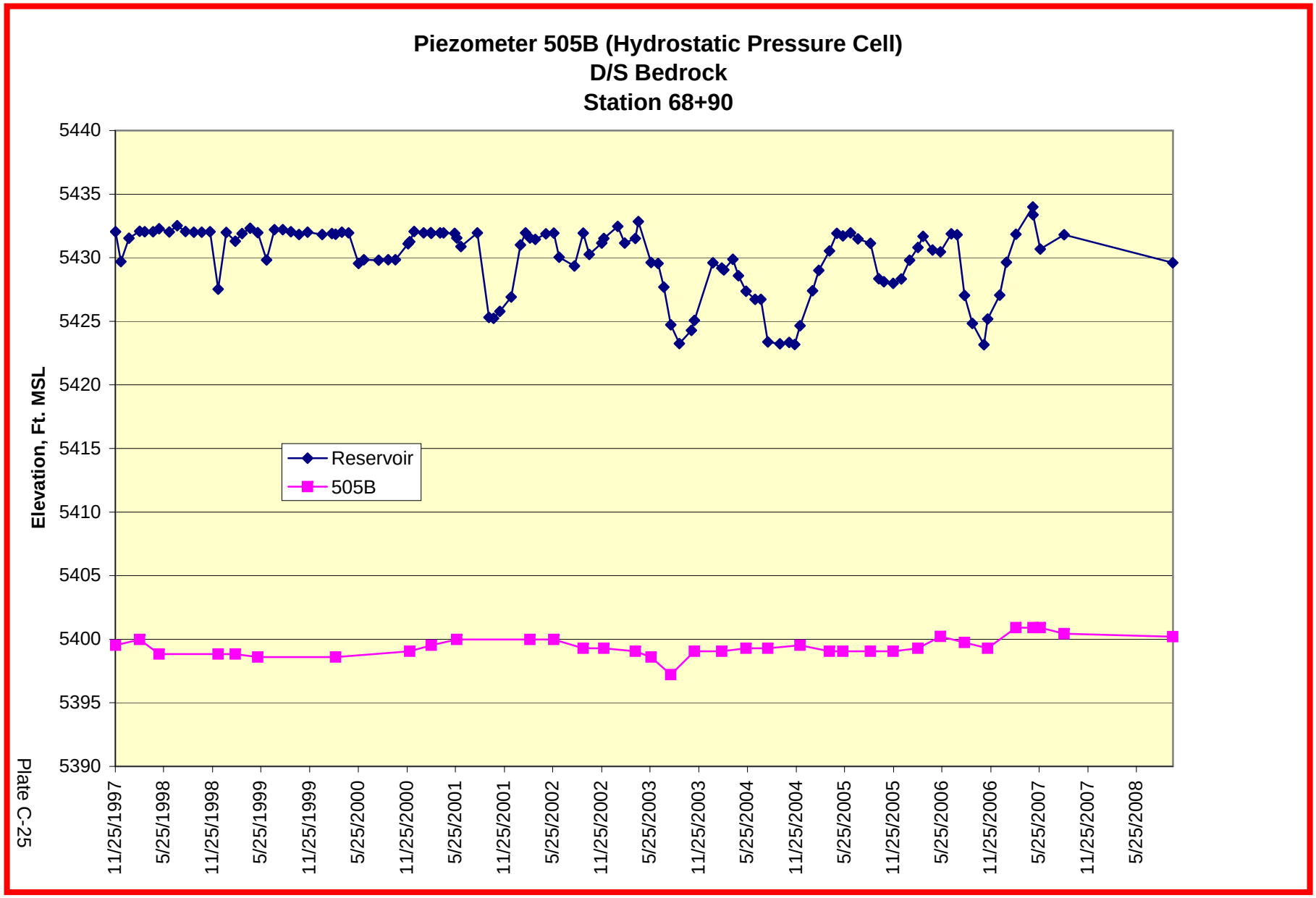

Piezometer 505A (Hydrostatic Pressure Cell)
D/S Bedrock
Station 68+90
Elevation, Ft. MSL
5440
5430
5420
5410
5400
5390
5380
Reservoir
505A
Assumed error
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09

PLATE C-24


Piezometer 505B (Hydrostatic Pressure Cell)
D/S Bedrock
Station 68+90
Elevation, Ft. MSL
5440
5435
5430
5425
5420
5415
5410
5405
5400
5395
5390
Reservoir
505B
11/25/1997
5/25/1998
11/25/1998
5/25/1999
11/25/1999
5/25/2000
11/25/2000
5/25/2001
11/25/2001
5/25/2002
11/25/2002
5/25/2003
11/25/2003
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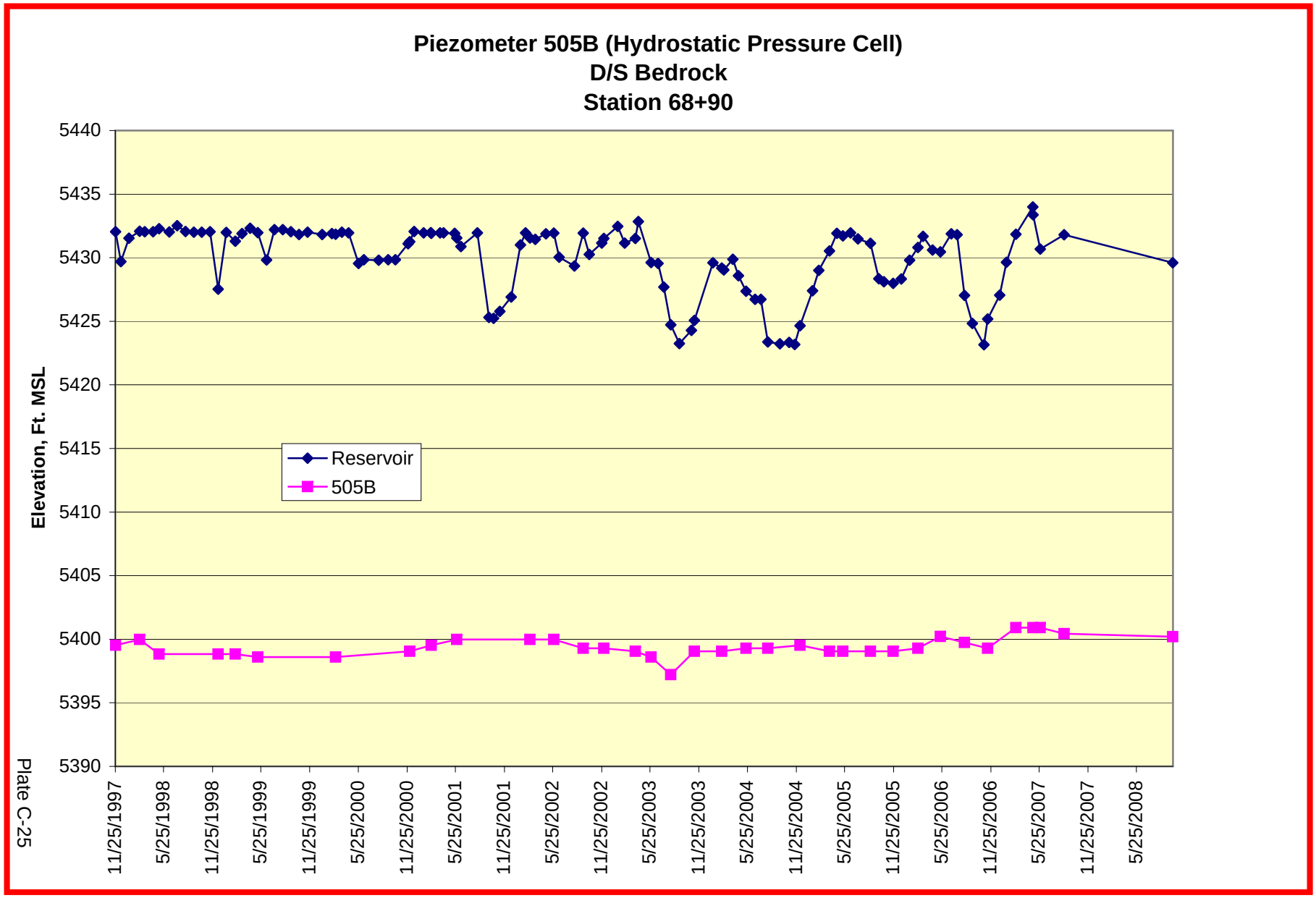
5/25/2007
11/25/2007
5/25/2008


Piezometer 505B (Hydrostatic Pressure Cell)
D/S Bedrock
Station 68+90
Elevation, Ft. MSL
5440
5435
5430
5425
5420
5415
5410
5405
5400
5395
5390
Reservoir
505B
11/25/1997
5/25/1998
11/25/1998
5/25/1999
11/25/1999
5/25/2000
11/25/2000
5/25/2001
11/25/2001
5/25/2002
11/25/2002
5/25/2003
11/25/2003
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11/25/2007
5/25/2008

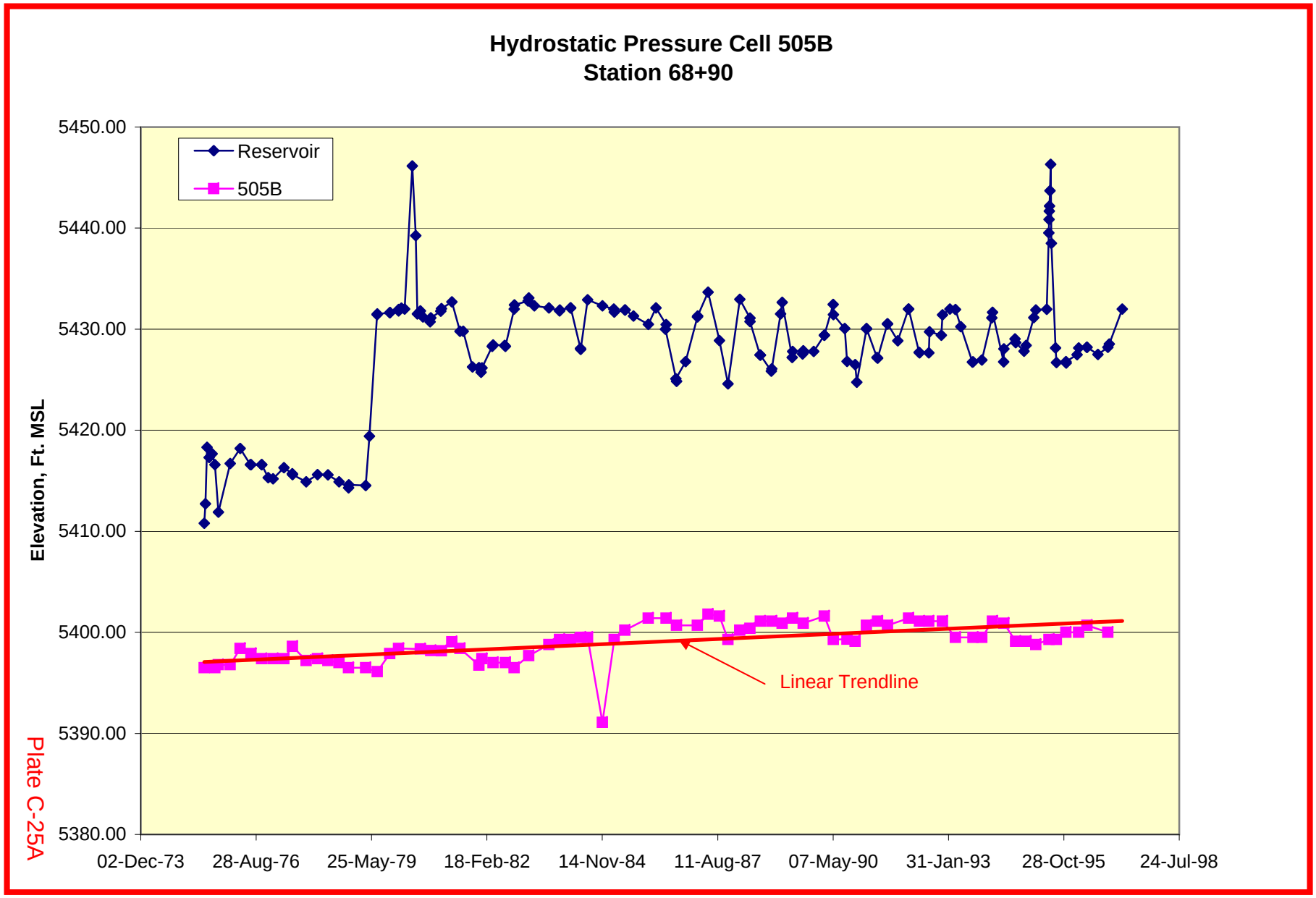
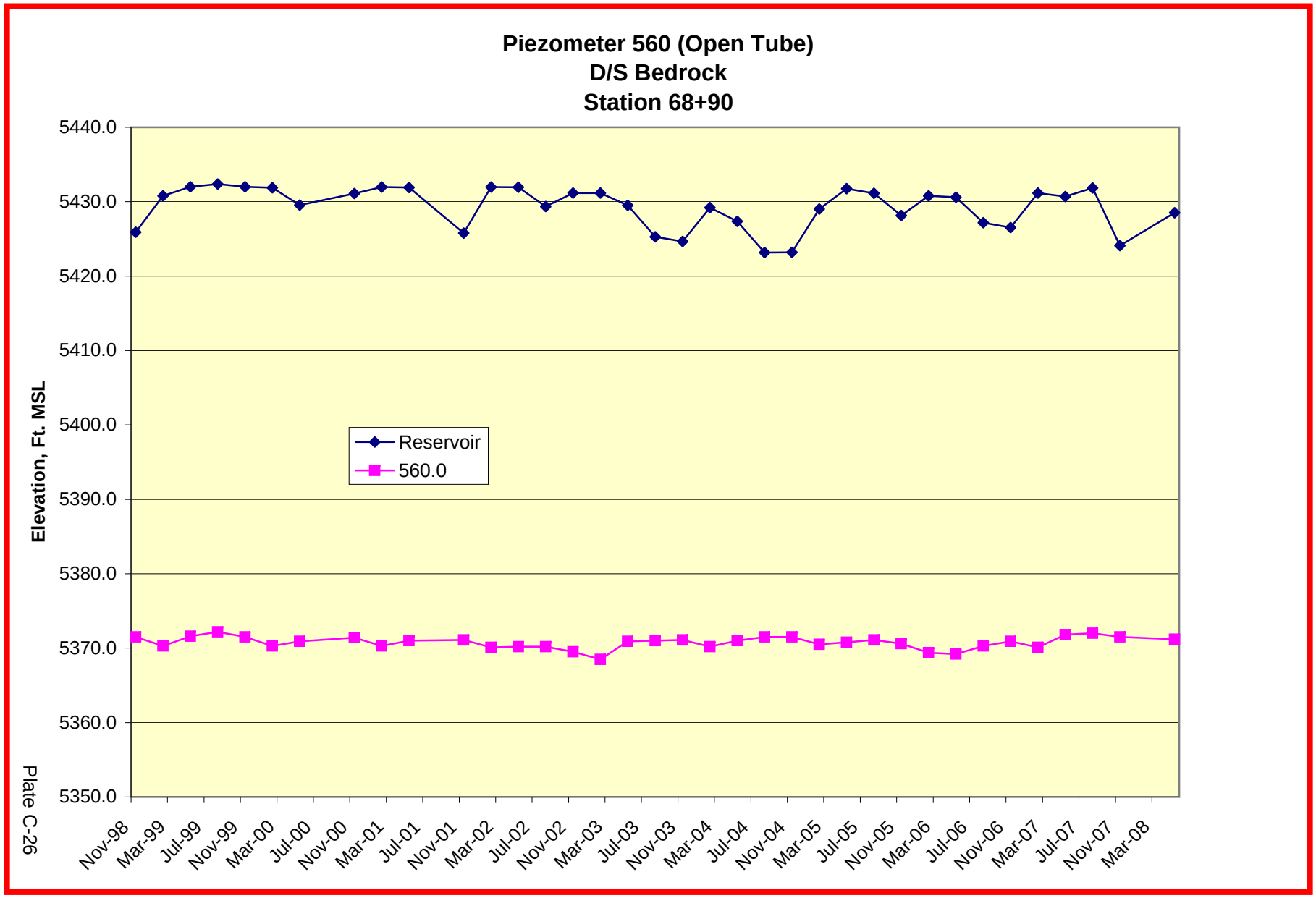
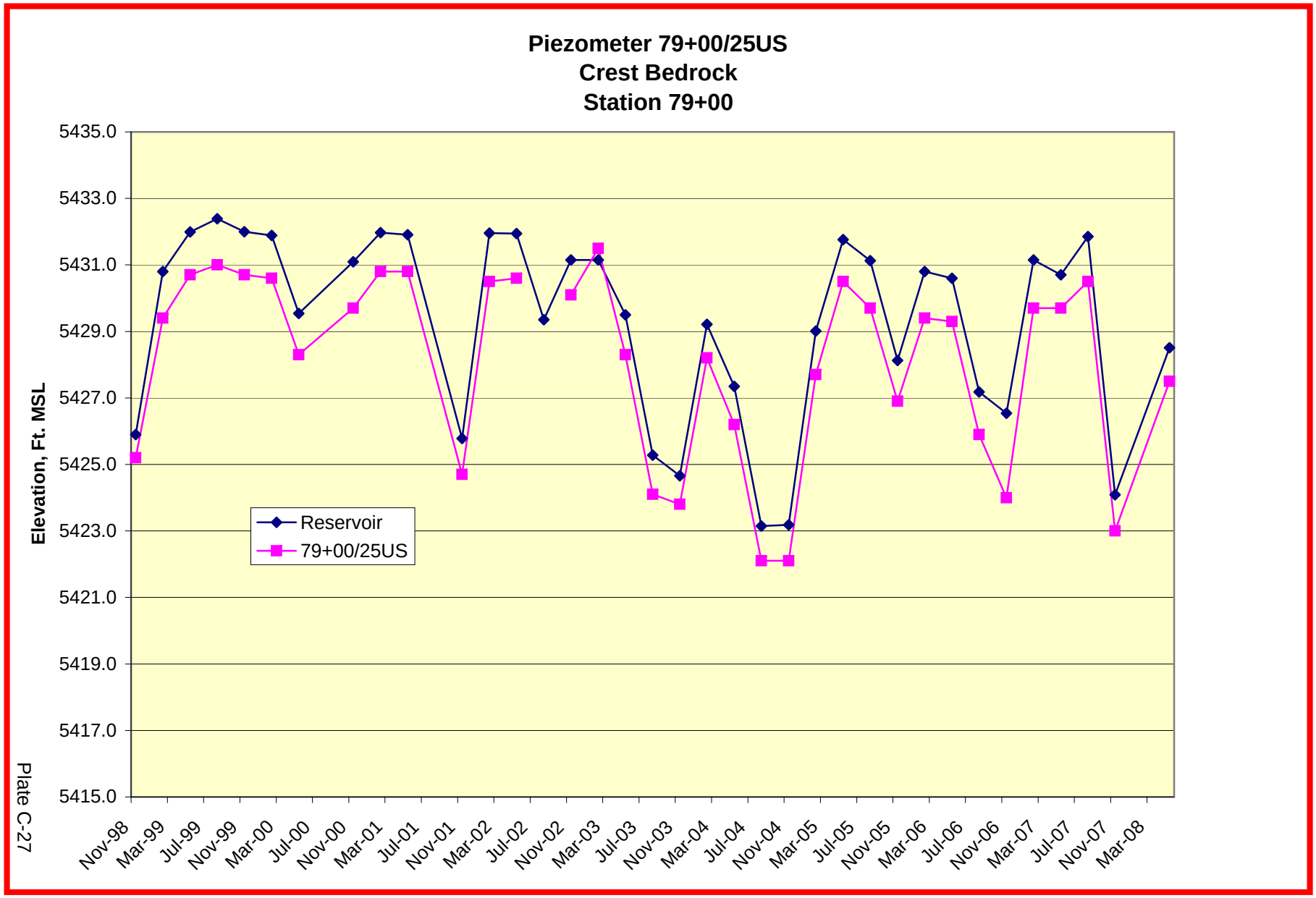

Hydrostatic Pressure Cell 505B
Station 68+90
Reservoir
505B
Linear Trendline
Elevation, Ft. MSL
5450.00
5440.00
5430.00
5420.00
5410.00
5400.00
5390.00
5380.00
02-Dec-73
28-Aug-76
25-May-79
18-Feb-82
14-Nov-84
11-Aug-87
07-May-90
31-Jan-93
28-Oct-95
24-Jul-98

Plate C-25A


Piezometer 560 (Open Tube)
D/S Bedrock
Station 68+90
Elevation, Ft. MSL
5440.0
5430.0
5420.0
5410.0
5400.0
5390.0
5380.0
5370.0
5360.0
5350.0
Reservoir
560.0
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 79+00/25US
Crest Bedrock
Station 79+00
Elevation, Ft. MSL
5435.0
5433.0
5431.0
5429.0
5427.0
5425.0
5423.0
5421.0
5419.0
5417.0
5415.0
Reservoir
79+00/25US
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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Jul-05
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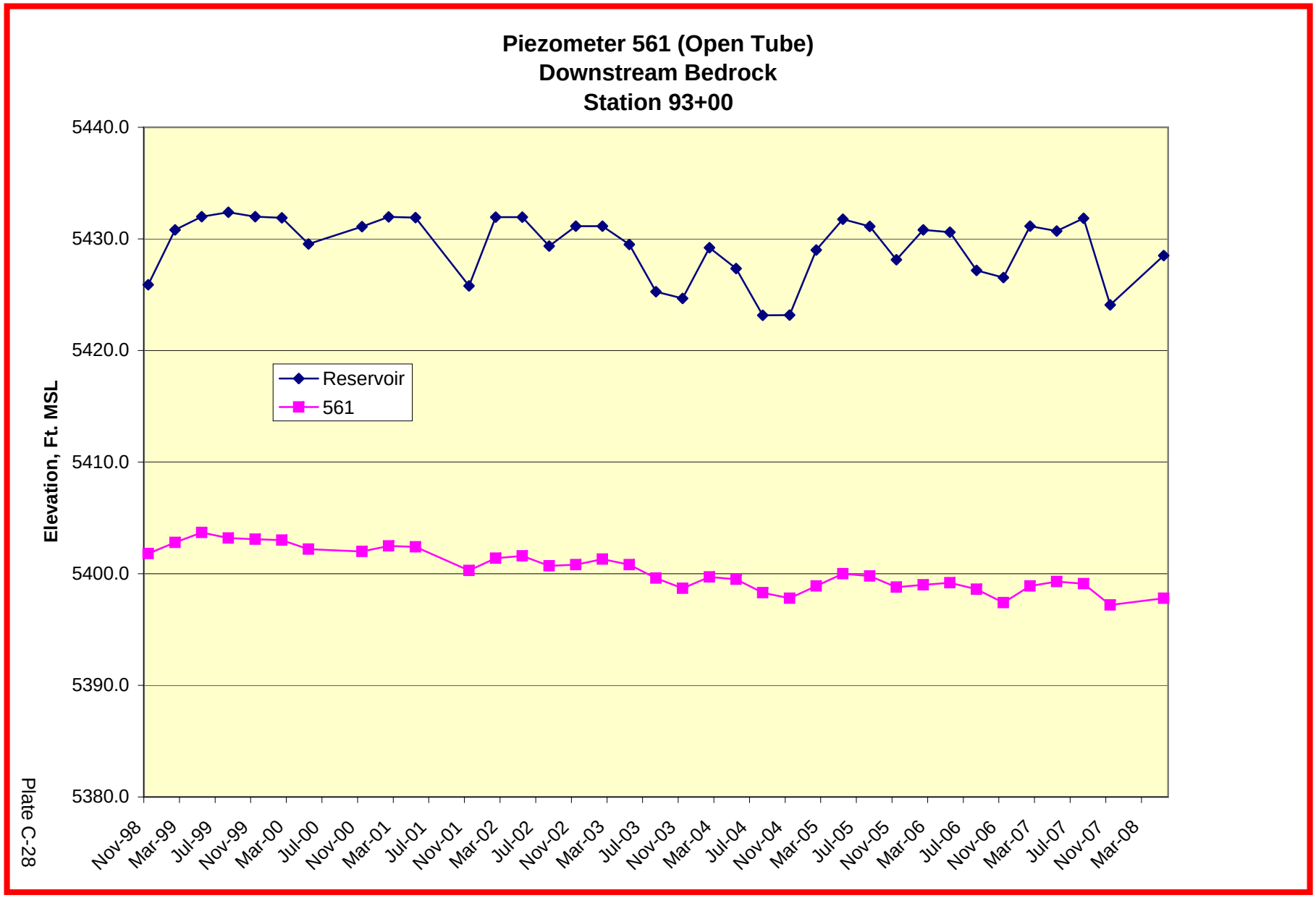
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 561 (Open Tube)
Downstream Bedrock
Station 93+00
Elevation, Ft. MSL
5440.0
5430.0
5420.0
5410.0
5400.0
5390.0
5380.0
Reservoir
561
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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Nov-06
Mar-07
Jul-07
Nov-07
Mar-08

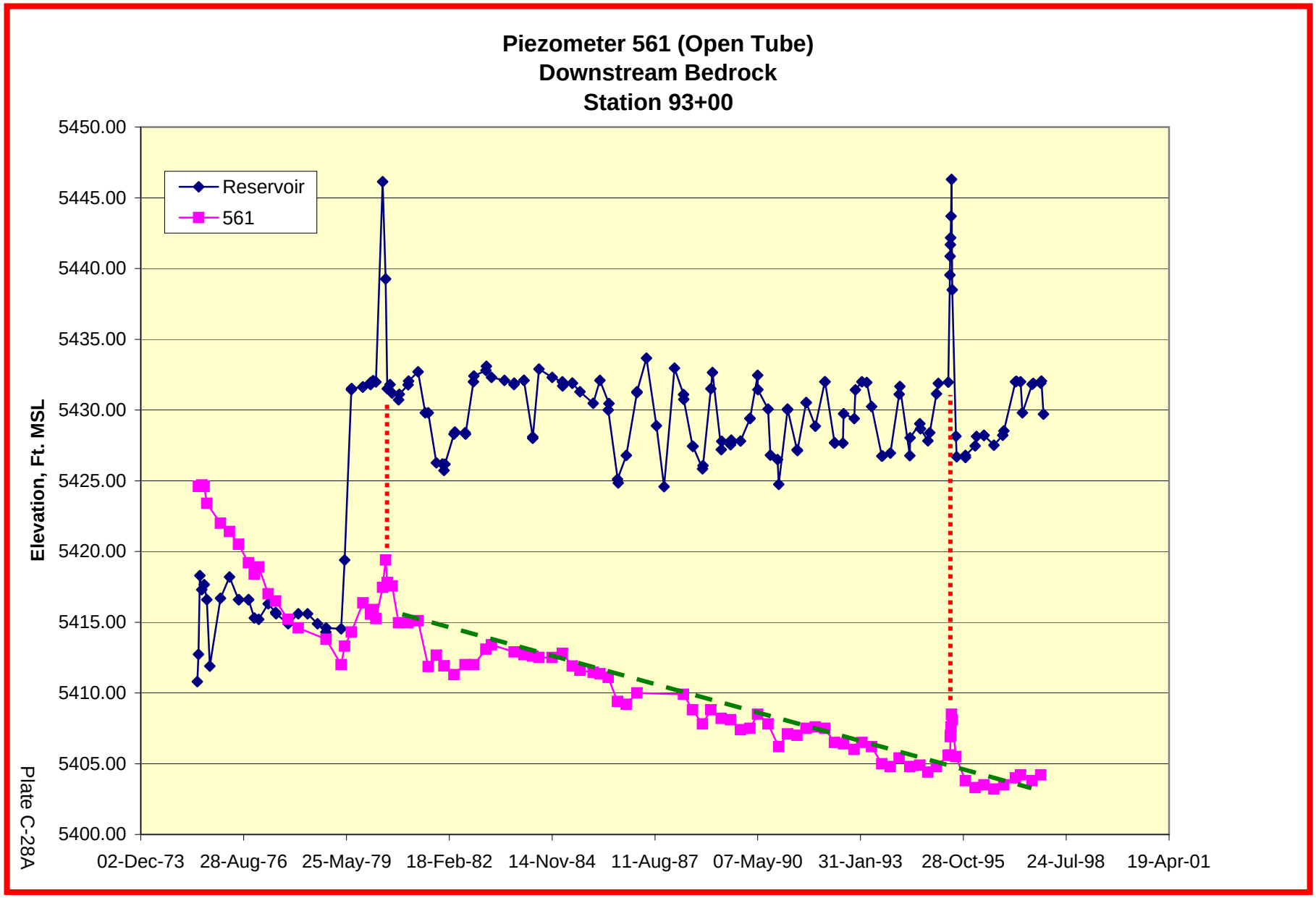
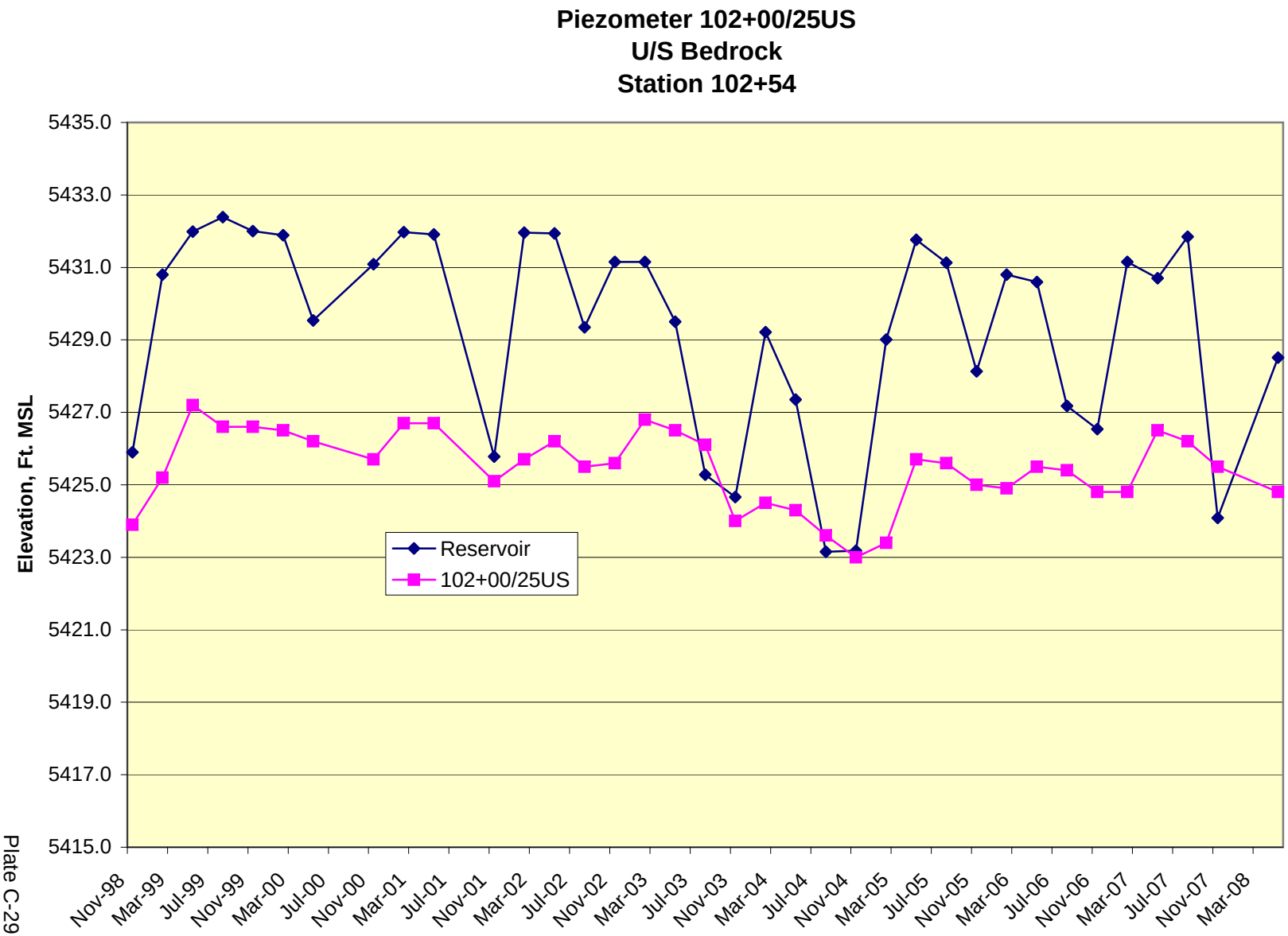

Piezometer 561 (Open Tube)
Downstream Bedrock
Station 93+00
Reservoir
561
Elevation, Ft. MSL
5450.00
5445.00
5440.00
5435.00
5430.00
5425.00
5420.00
5415.00
5410.00
5405.00
5400.00
02-Dec-73
28-Aug-76
25-May-79
18-Feb-82
14-Nov-84
11-Aug-87
07-May-90
31-Jan-93
28-Oct-95
24-Jul-98
19-Apr-01

Plate C-28A


Piezometer 102+00/25US
U/S Bedrock
Station 102+54
Elevation, Ft. MSL
5435.0
5433.0
5431.0
5429.0
5427.0
5425.0
5423.0
5421.0
5419.0
5417.0
5415.0
Reservoir
102+00/25US
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
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Jul-05
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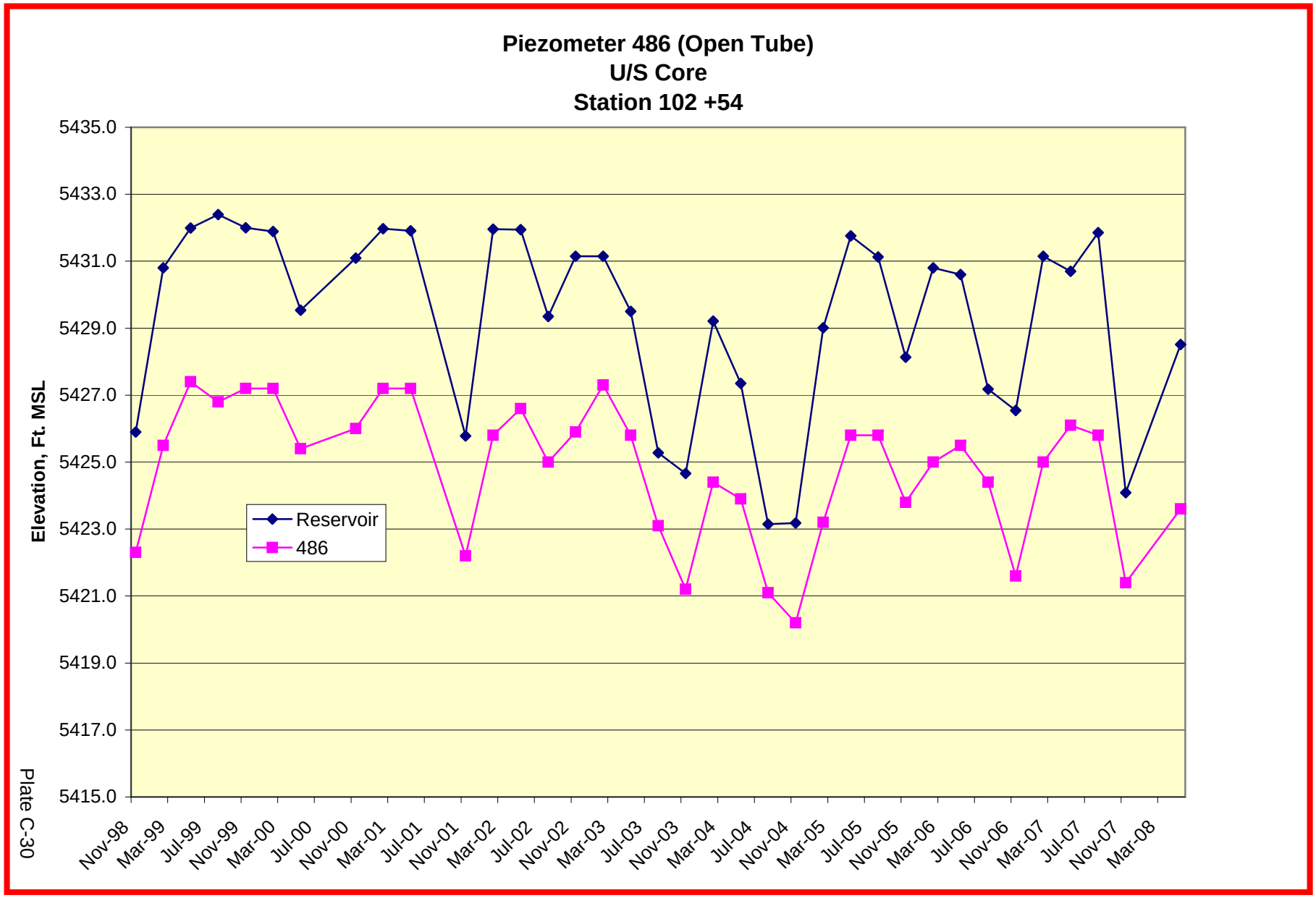
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 486 (Open Tube)
U/S Core
Station 102 +54
Elevation, Ft. MSL
5435.0
5433.0
5431.0
5429.0
5427.0
5425.0
5423.0
5421.0
5419.0
5417.0
5415.0
Reservoir
486
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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Mar-07
Jul-07
Nov-07
Mar-08

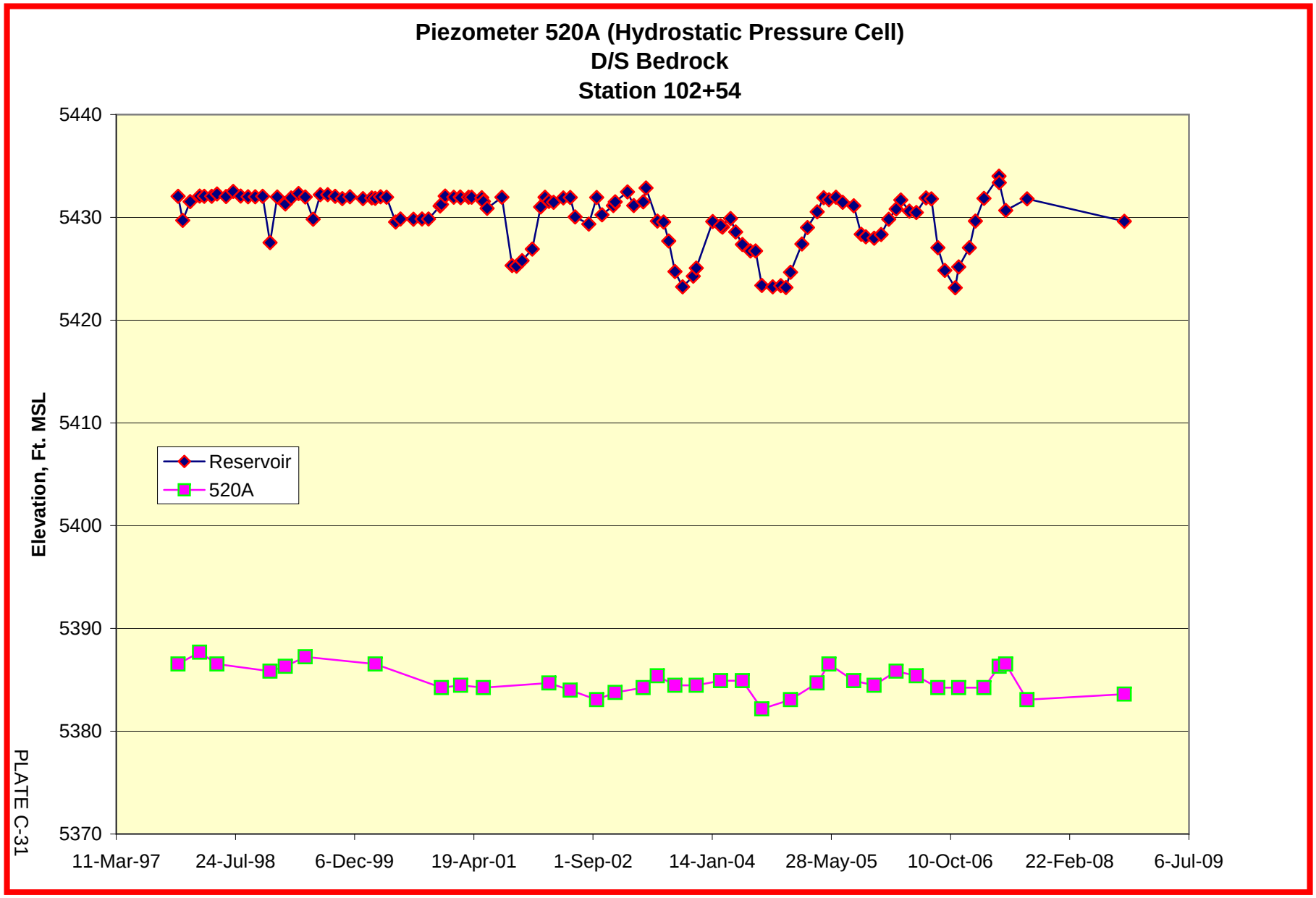

Piezometer 520A (Hydrostatic Pressure Cell)
D/S Bedrock
Station 102+54
Elevation, Ft. MSL
5440
5430
5420
5410
5400
5390
5380
5370
Reservoir
520A
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09

PLATE C-31

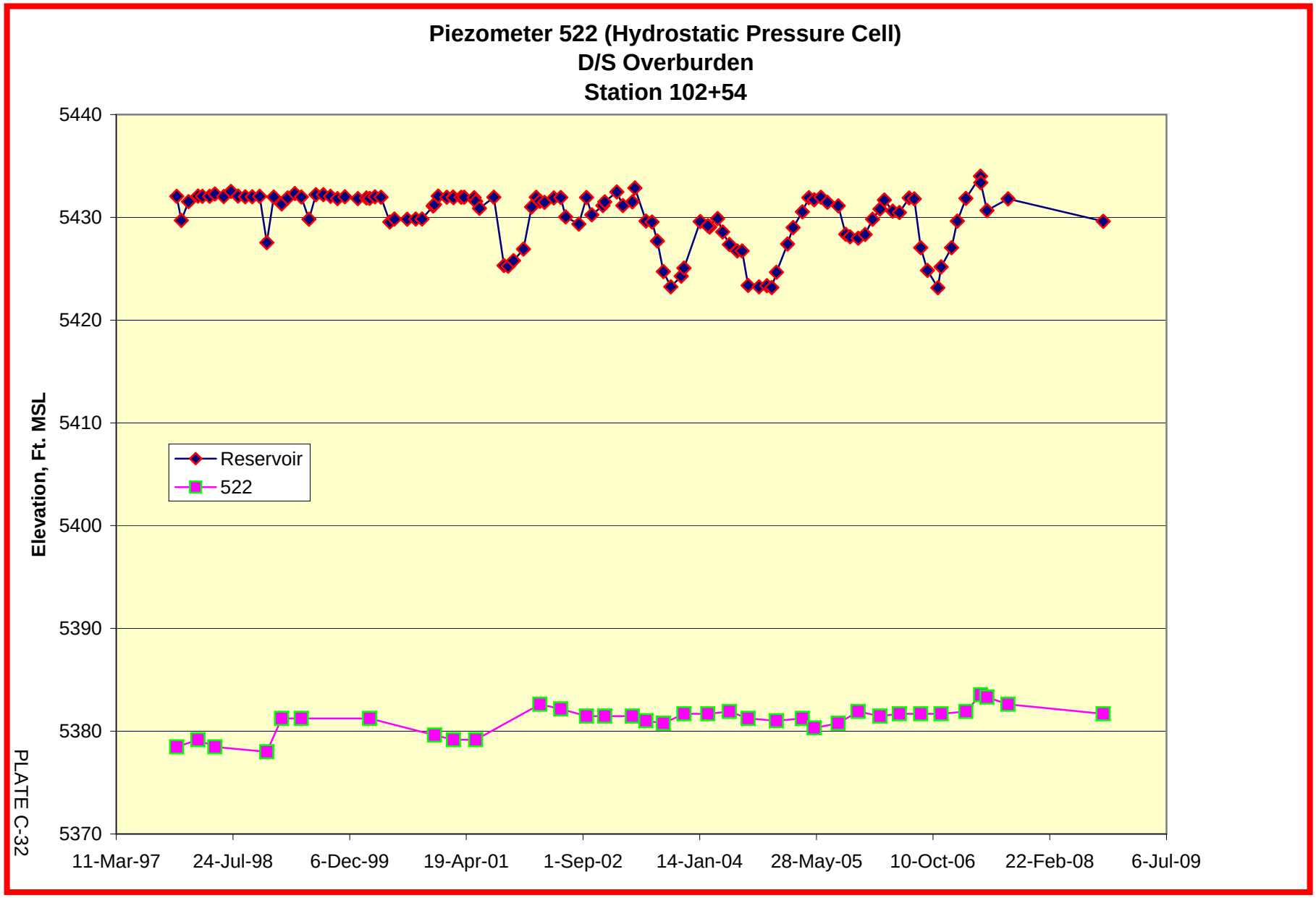
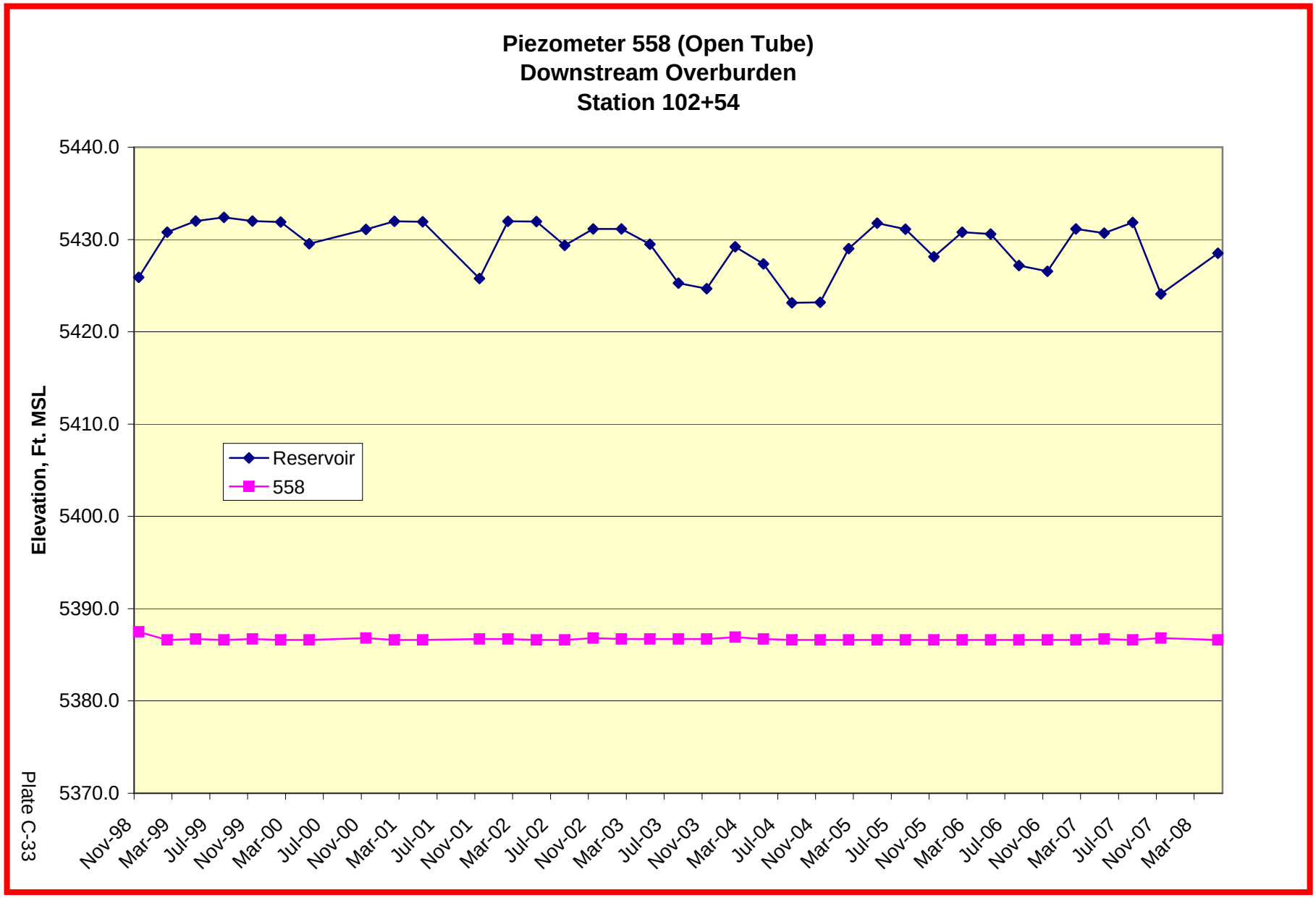

Piezometer 522 (Hydrostatic Pressure Cell)
D/S Overburden
Station 102+54
Elevation, Ft. MSL
5440
5430
5420
5410
5400
5390
5380
5370
Reservoir
522
11-Mar-97
24-Jul-98
6-Dec-99
19-Apr-01
1-Sep-02
14-Jan-04
28-May-05
10-Oct-06
22-Feb-08
6-Jul-09

PLATE C-32


Piezometer 558 (Open Tube)
Downstream Overburden
Station 102+54
Elevation, Ft. MSL
5440.0
5430.0
5420.0
5410.0
5400.0
5390.0
5380.0
5370.0
Reservoir
558
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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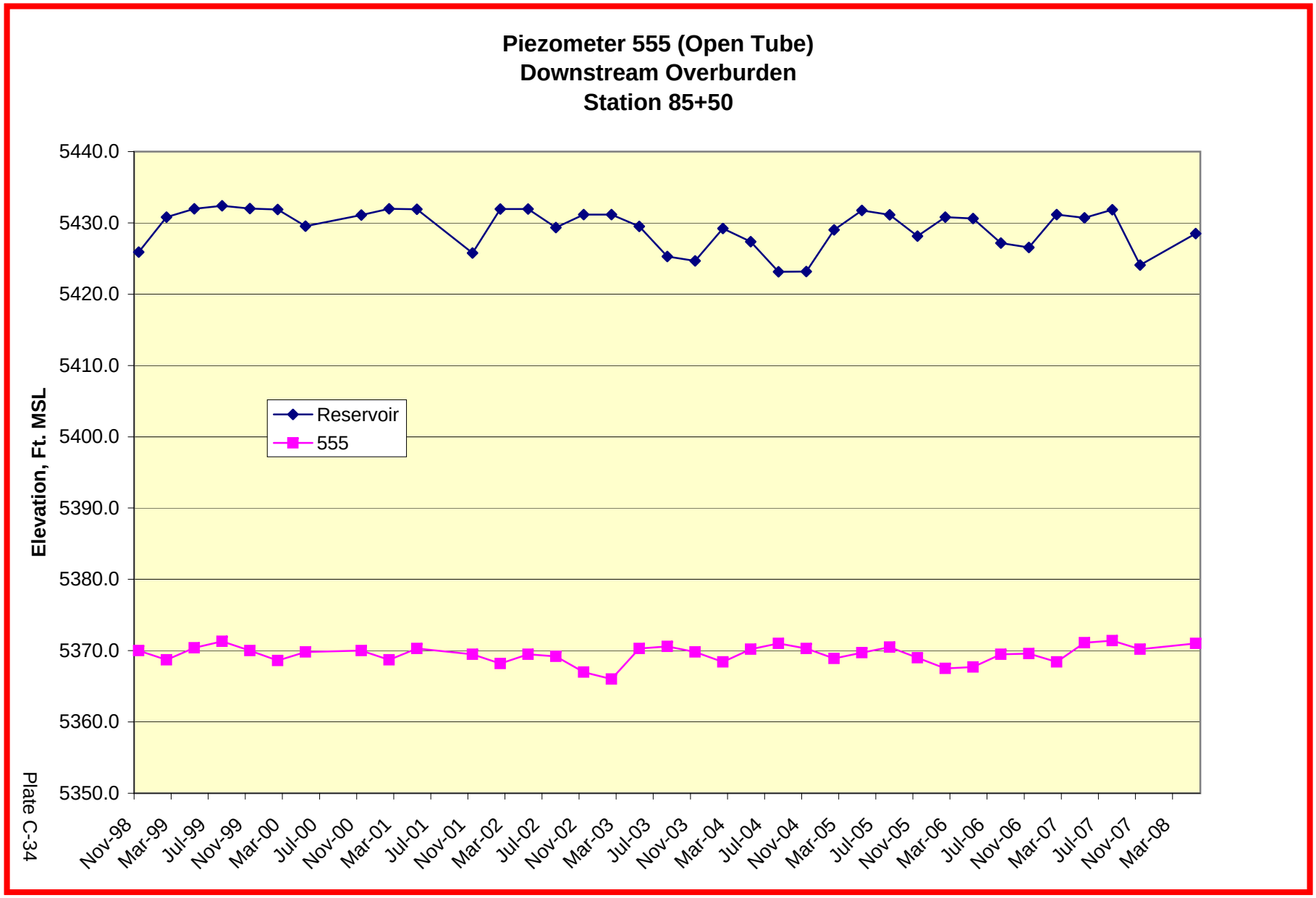
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 555 (Open Tube)
Downstream Overburden
Station 85+50
Elevation, Ft. MSL
5440.0
5430.0
5420.0
5410.0
5400.0
5390.0
5380.0
5370.0
5360.0
5350.0
Reservoir
555
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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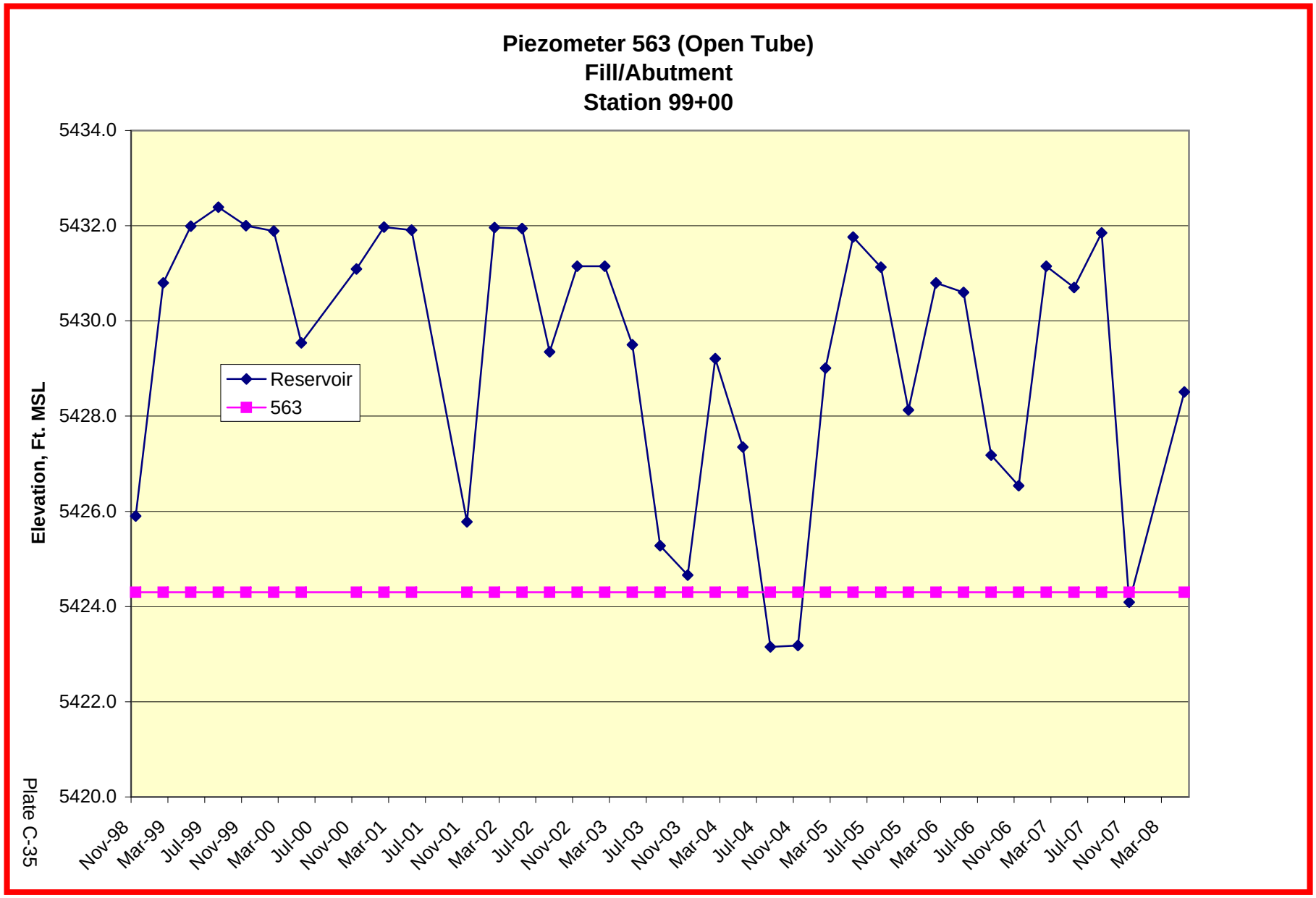
Mar-07
Jul-07
Nov-07
Mar-08


Piezometer 563 (Open Tube)
Fill/Abutment
Station 99+00
Elevation, Ft. MSL
5434.0
5432.0
5430.0
5428.0
5426.0
5424.0
5422.0
5420.0
Reservoir
563
Nov-98
Mar-99
Jul-99
Nov-99
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
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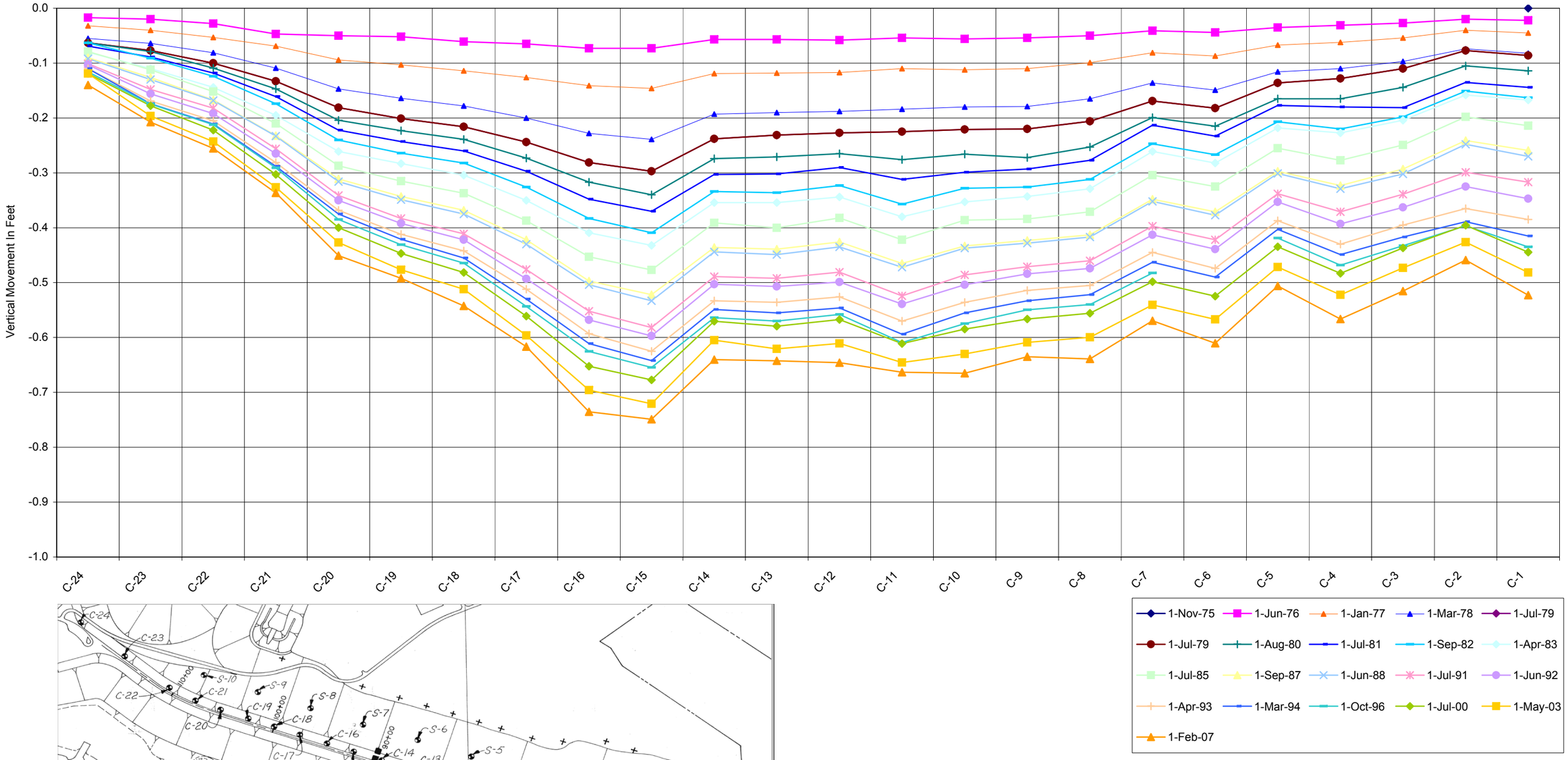
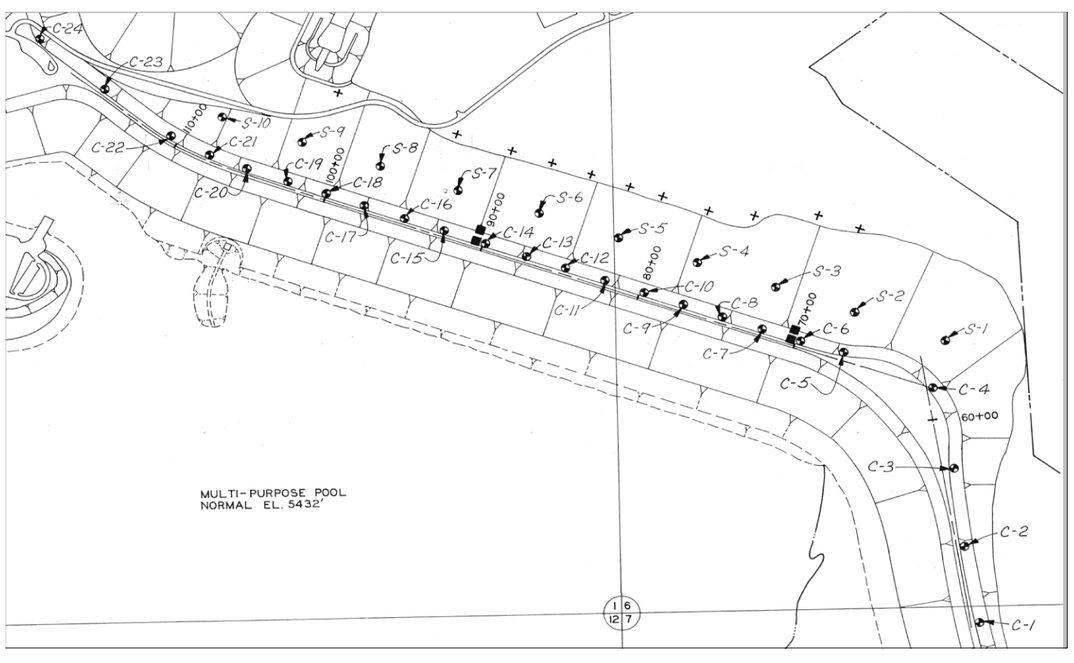
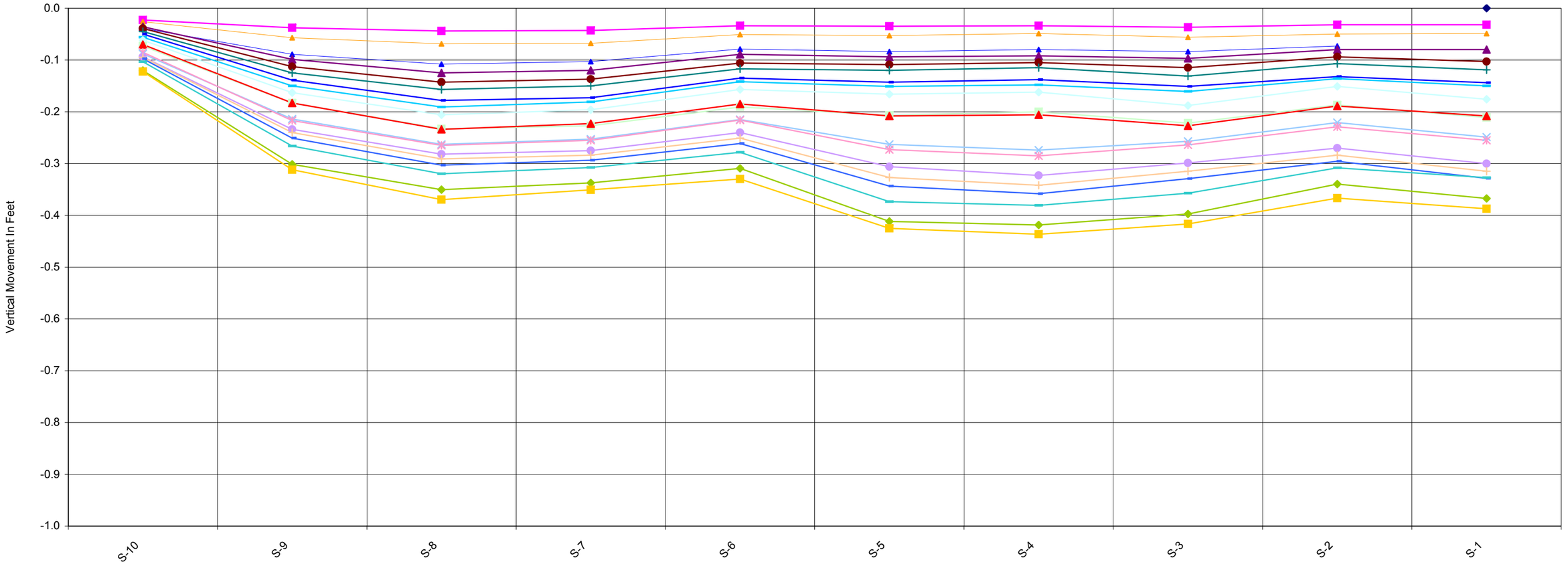
Mar-07
Jul-07
Nov-07
Mar-08

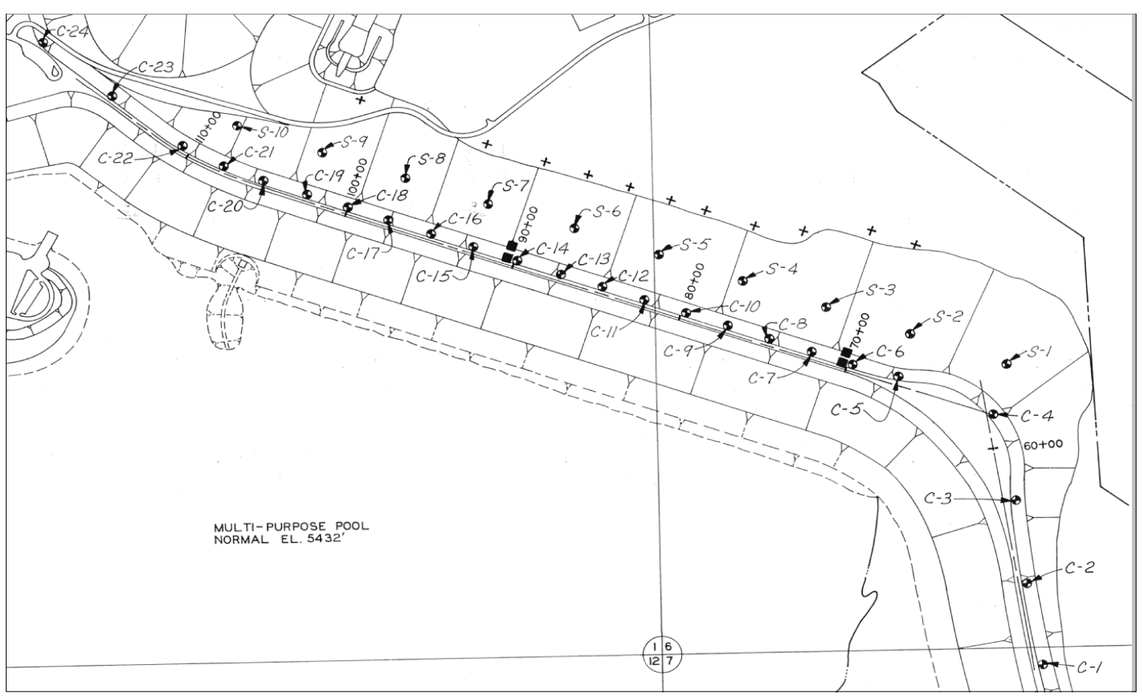




Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest Movement Markers
Vertical Movement

Re-Allocation Study Plate D-1

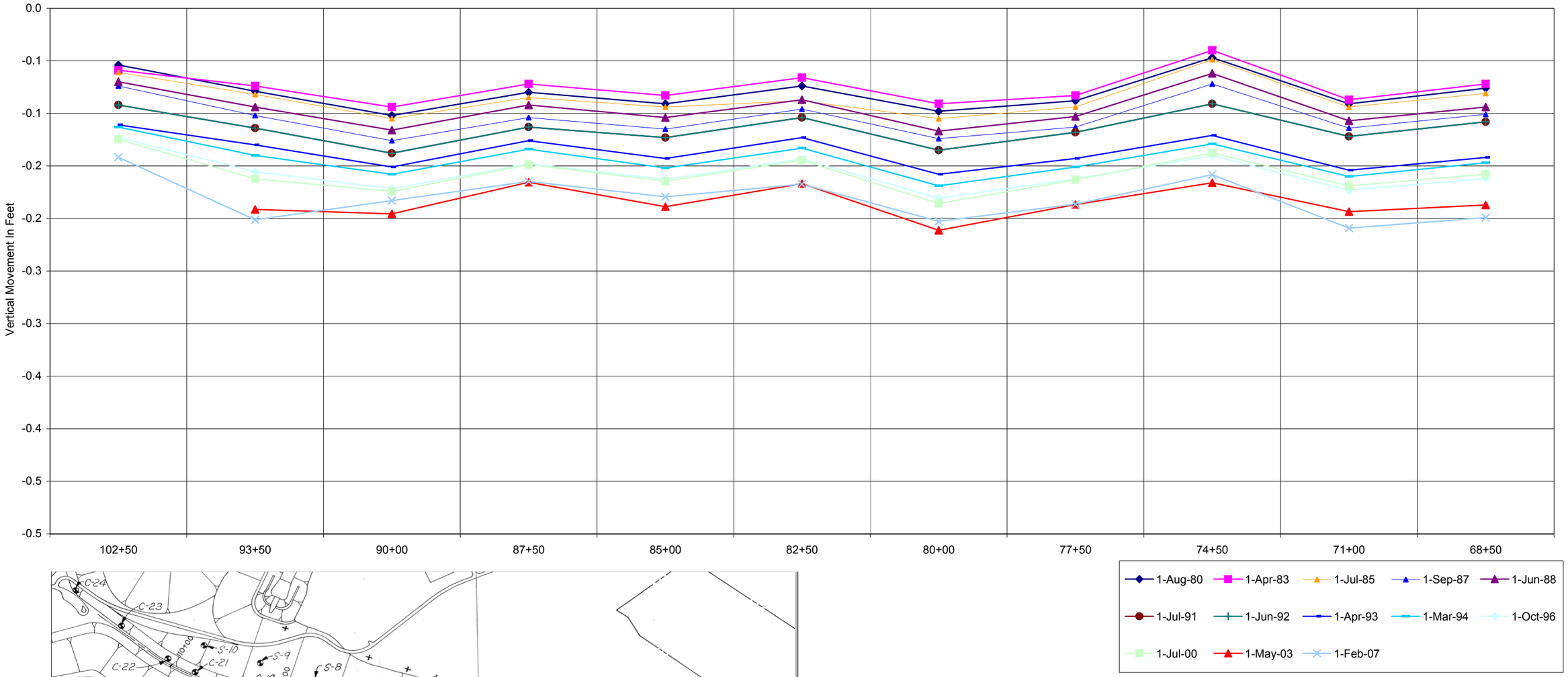


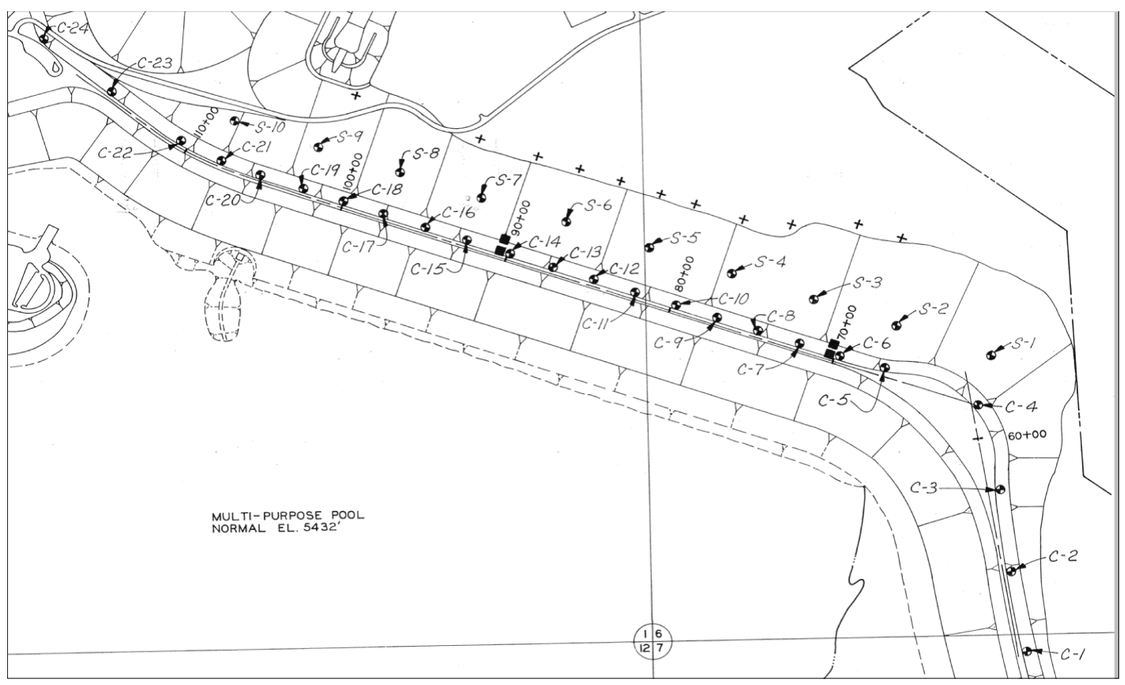


Notes:
1. Marker S-10 was found damaged and was reset August 1987.

Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Slope Movement Markers
Vertical Movement

Re-Allocation Study Plate D-2

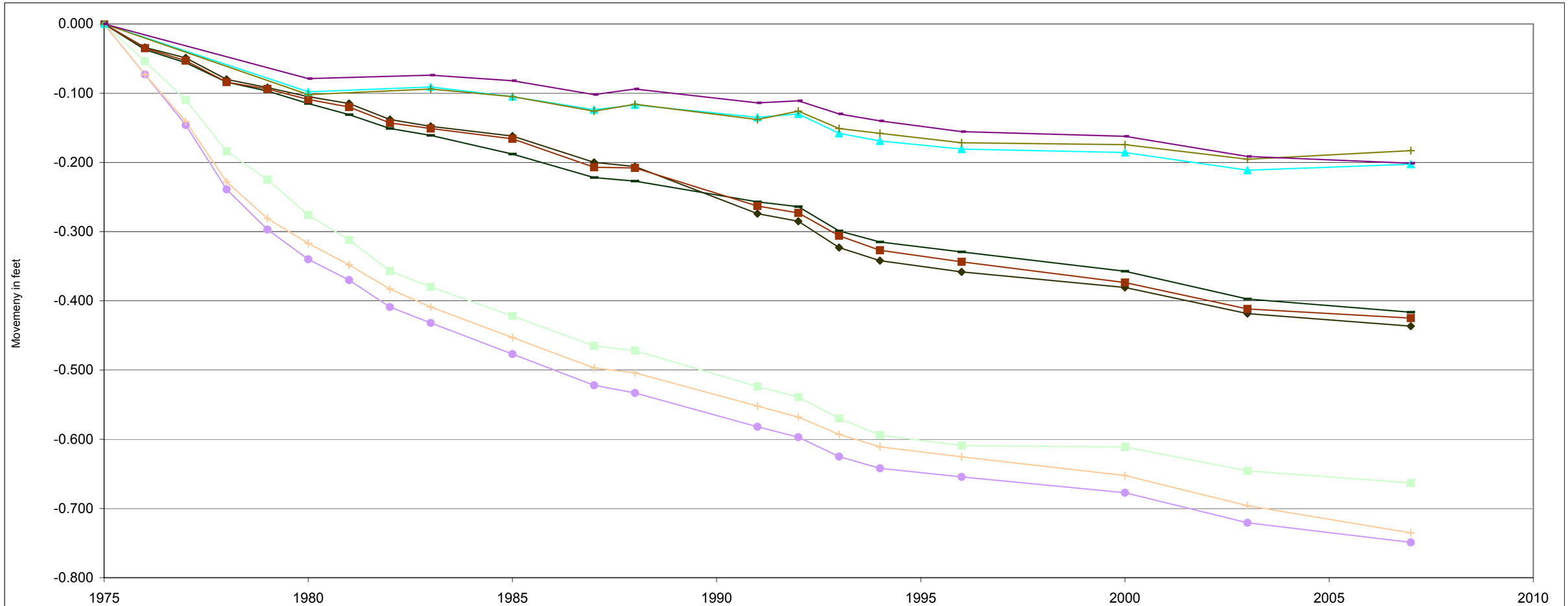


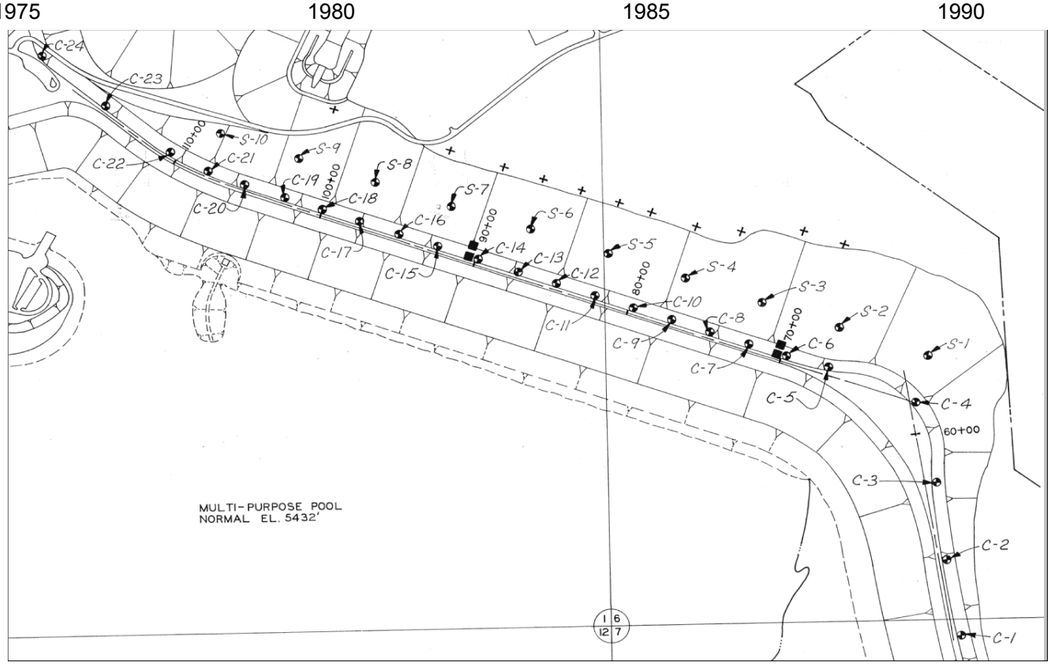


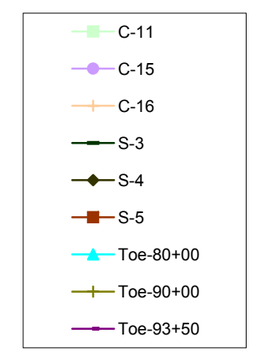
Notes:
1. 77+50 damaged and reset 8-24-71
2. 102+50 Initial 1974

Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Toe Movement Markers
Vertical Movement

Re-Allocation Study Plate D-3

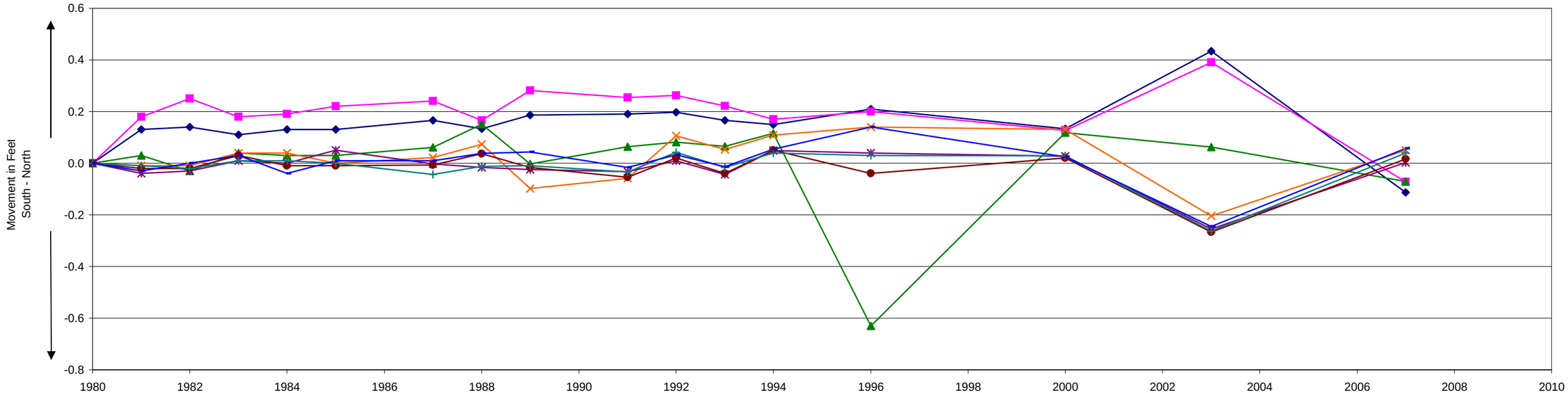


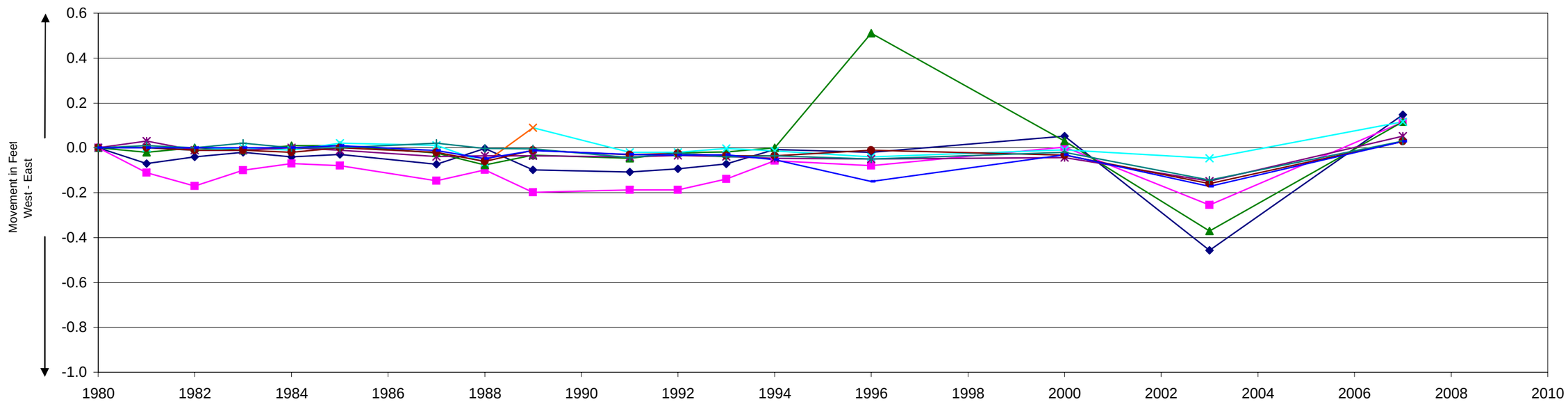




Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest, Slope and Toe Movement Markers
Vertical Movement vs. Time Plot

Re-Allocation Study Plate D-4

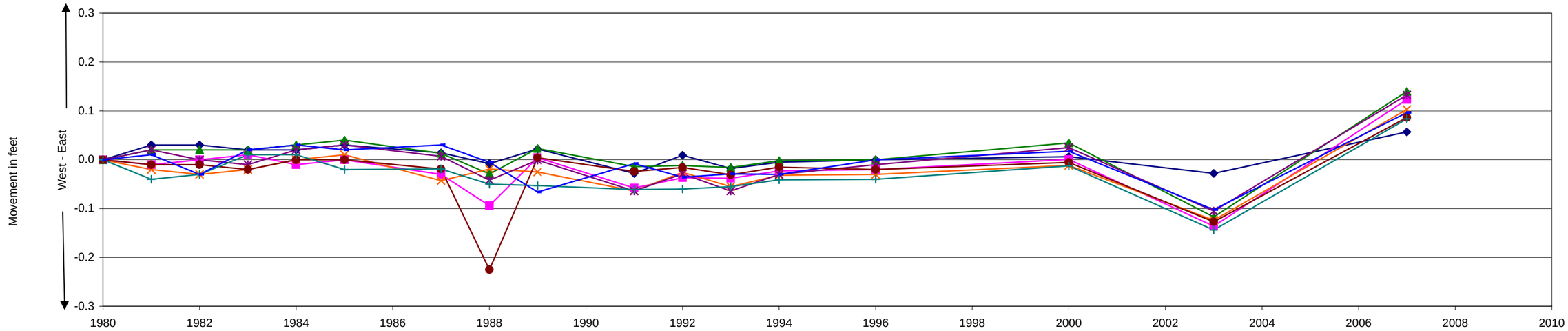


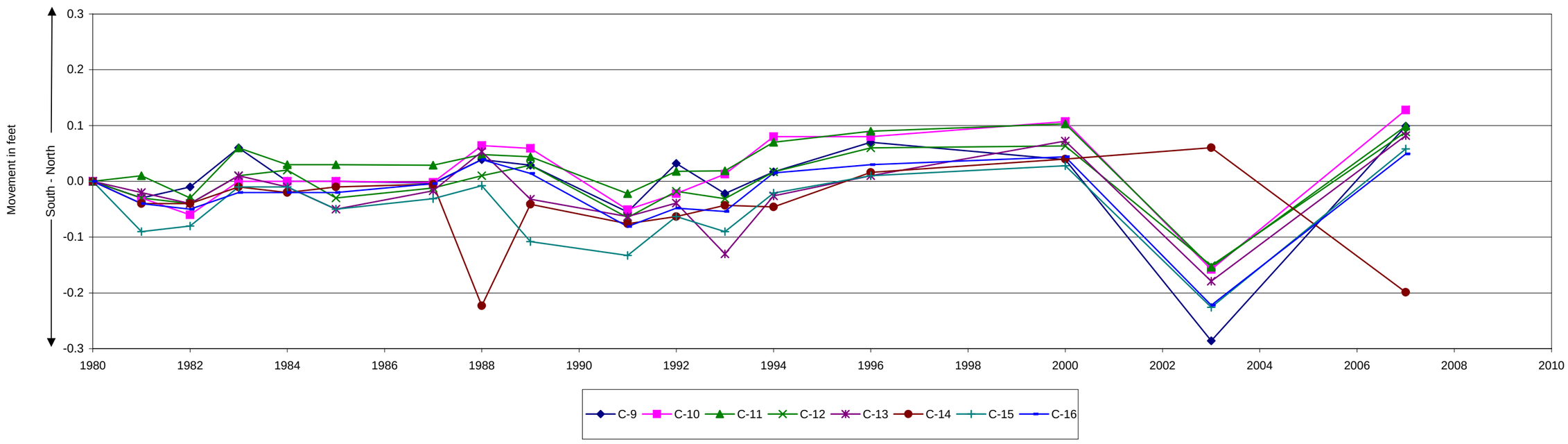


C-1 C-2 C-3 C-4 C-5 C-6 C-7 C-8

Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest, Slope, and Toe Movement Markers
Horizontal Movement vs Time Plot Crest Markers 1-

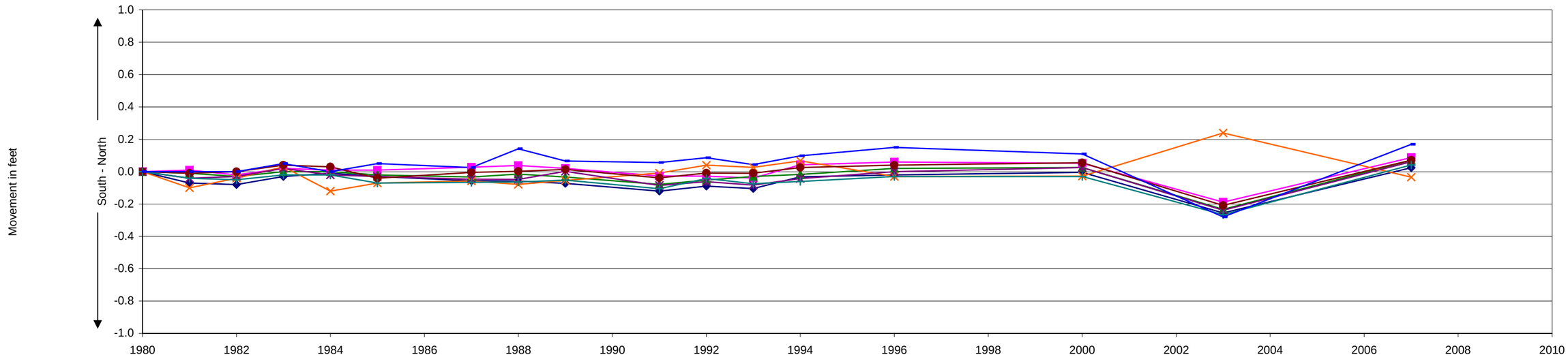
Re-Allocation Study Plate D-5

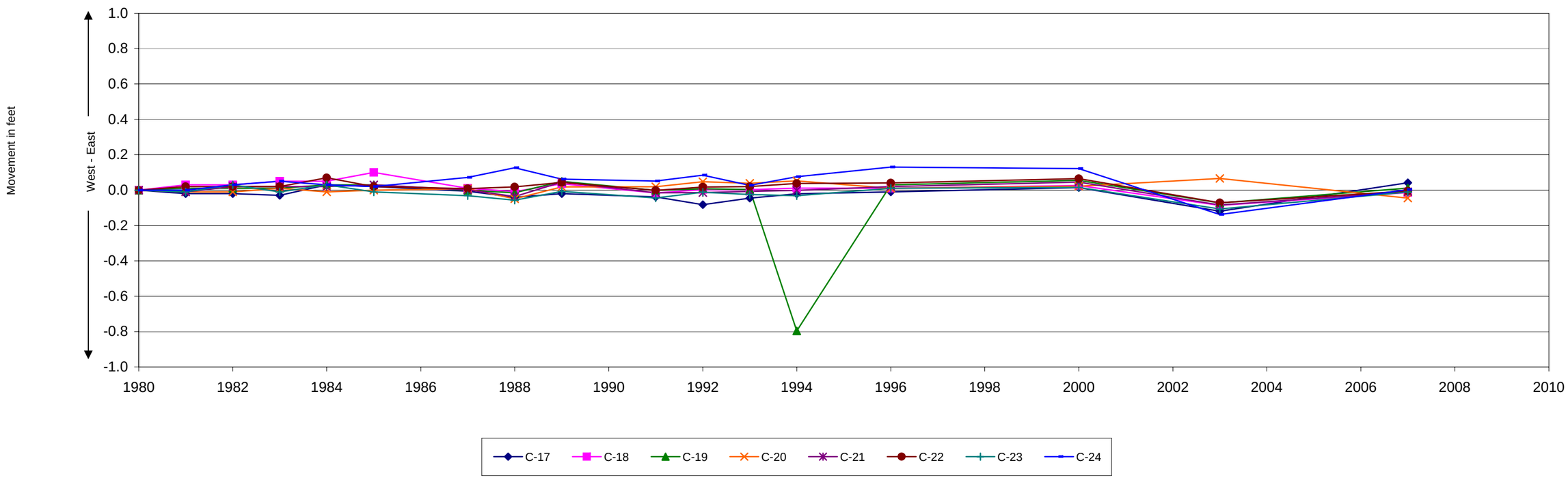




Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest, Slope, and Toe Movement Markers
Horizontal Movement vs. Time Plot Crest Markers 9-16

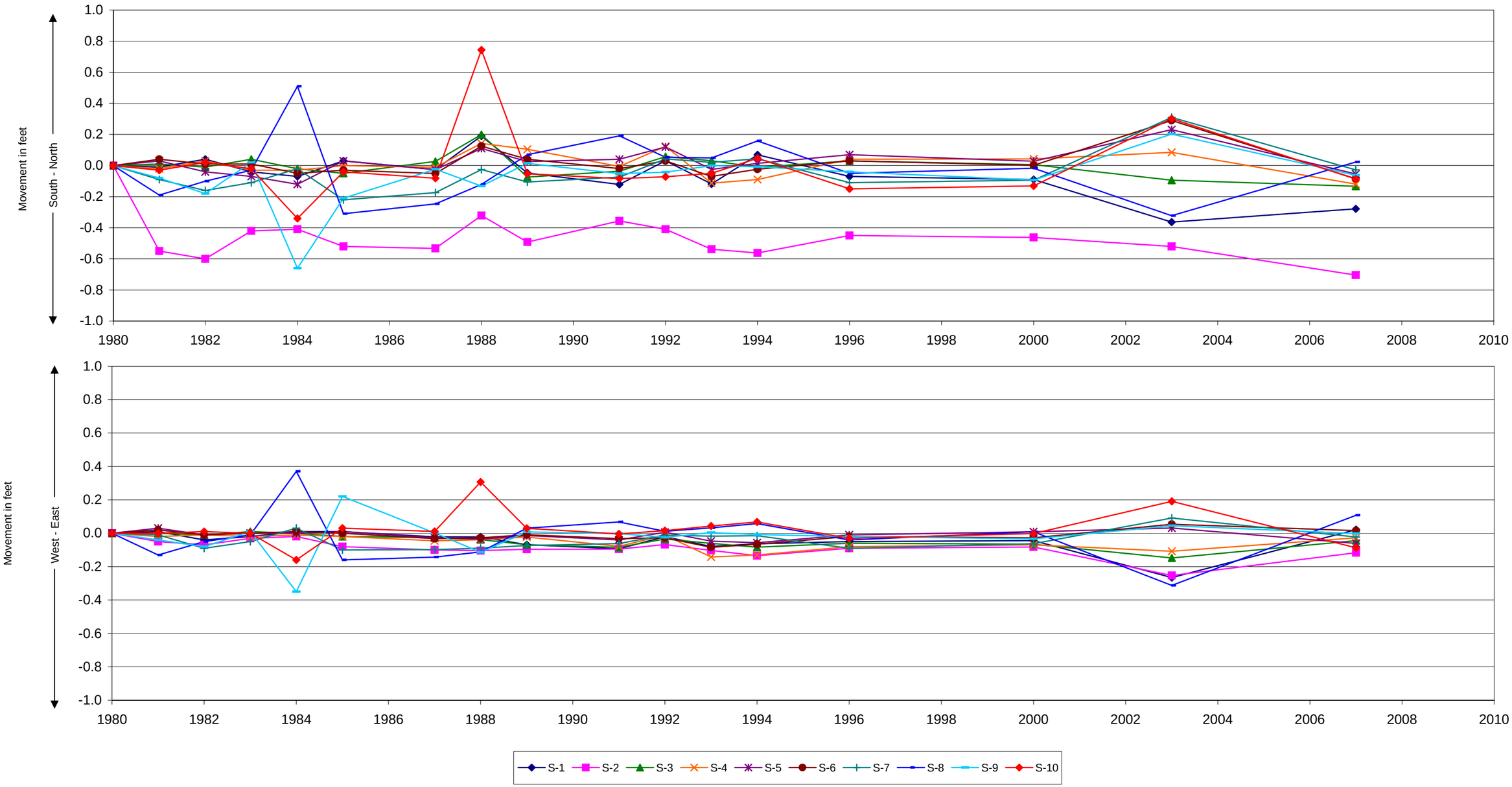
Re-Allocation Study Plate D-6





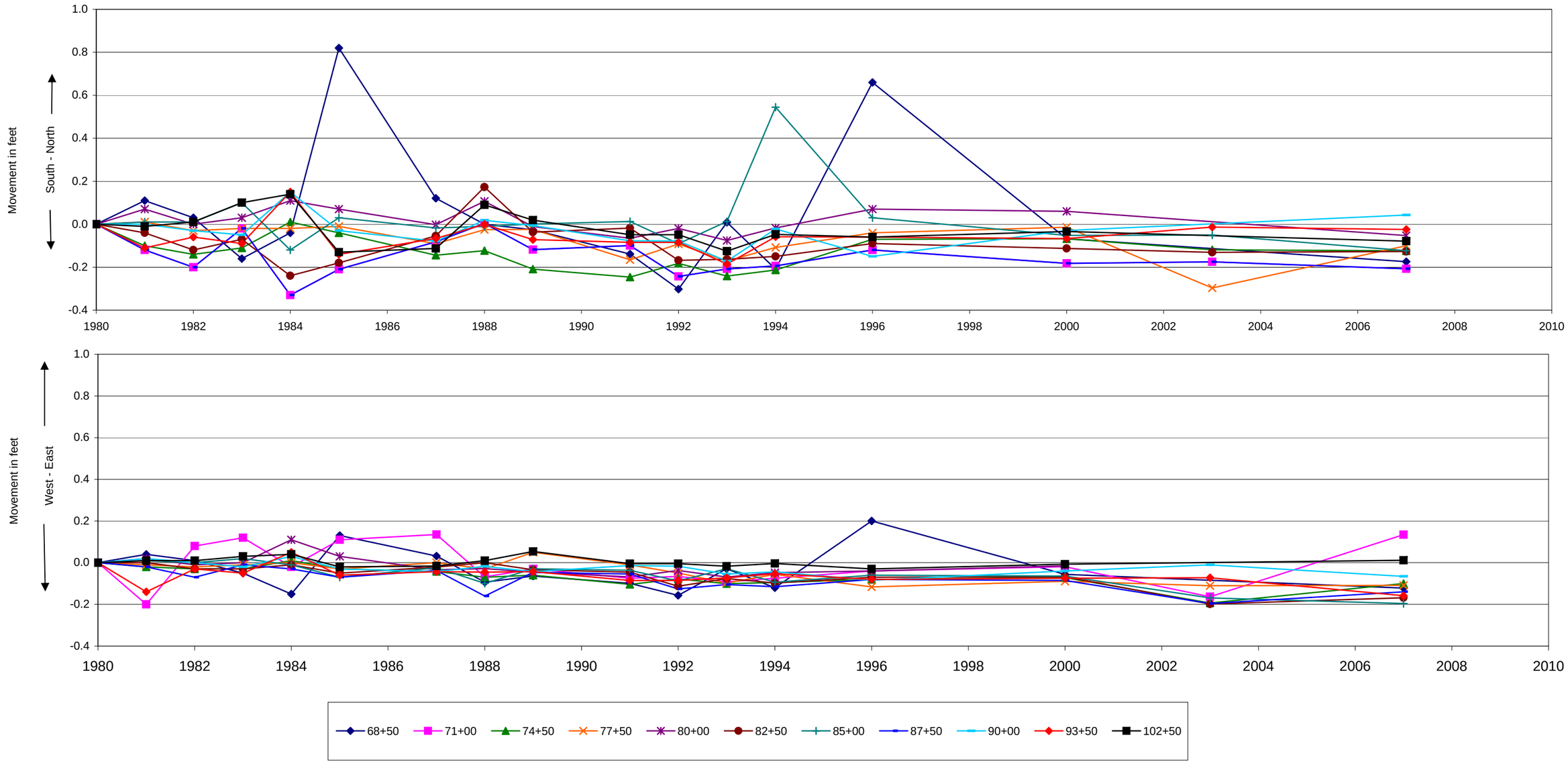
Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest, Slope, and Toe Movement Markers
Horizontal Movement vs Time Plot Crest Makers 17-24

Re-Allocation Study Plate D-7



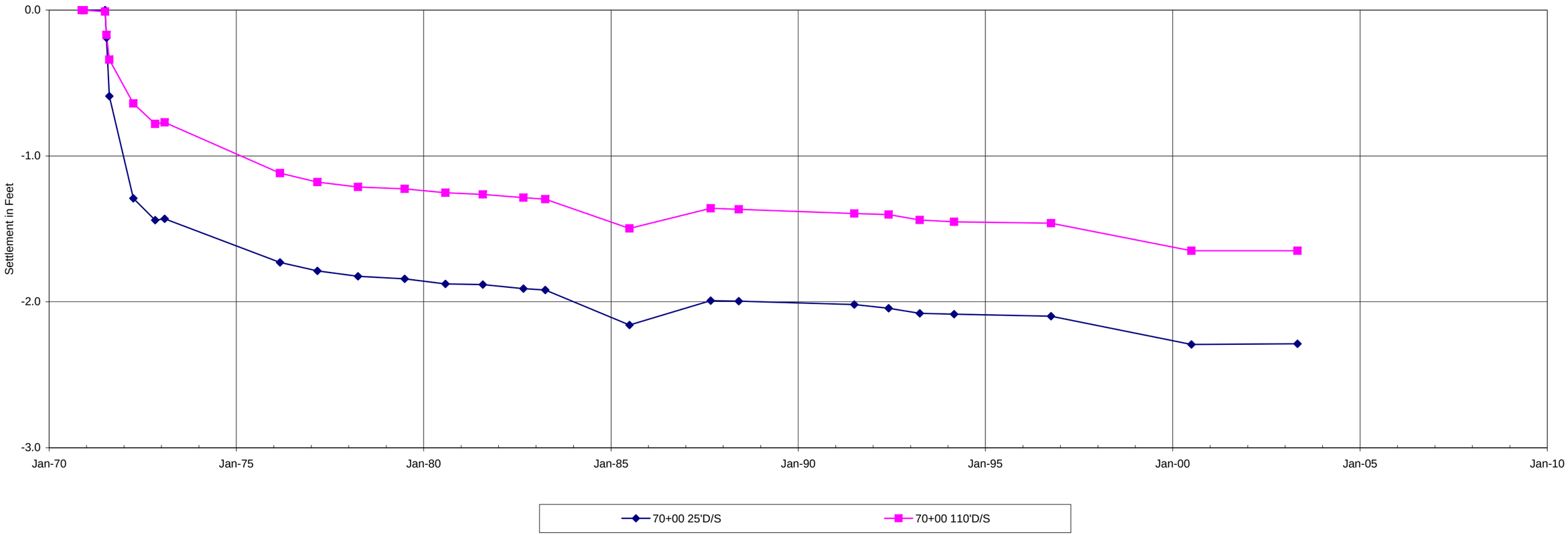
Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest, Slope, and Toe Movement Markers
Horizontal Movement vs. Time Plot

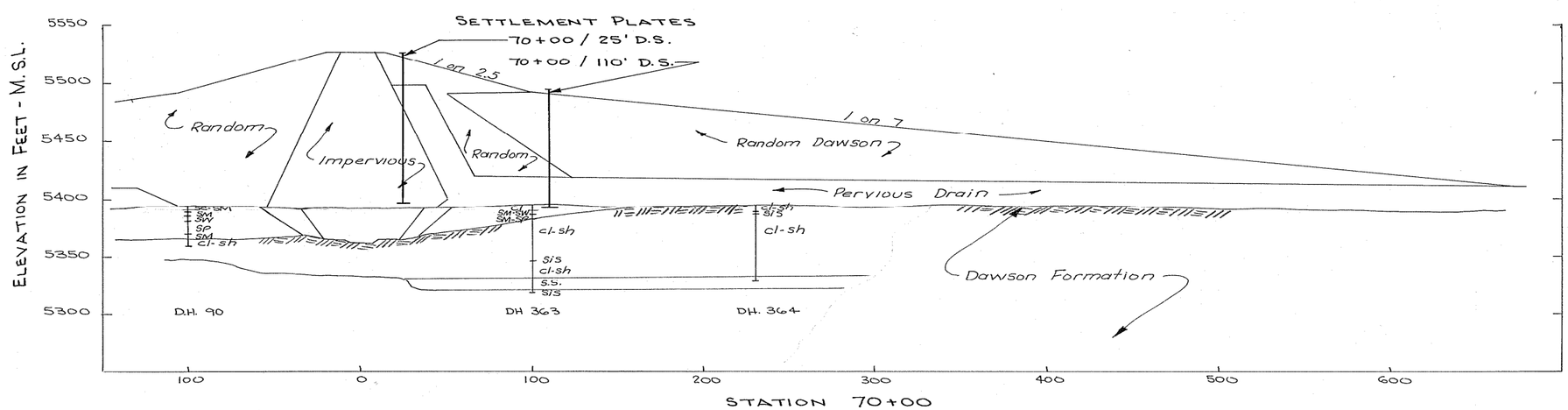
Re-Allocation Study Plate D-8



Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Crest, Slope, and Toe Movement Markers
Horizontal Movement vs. Time Plot Toe Markers

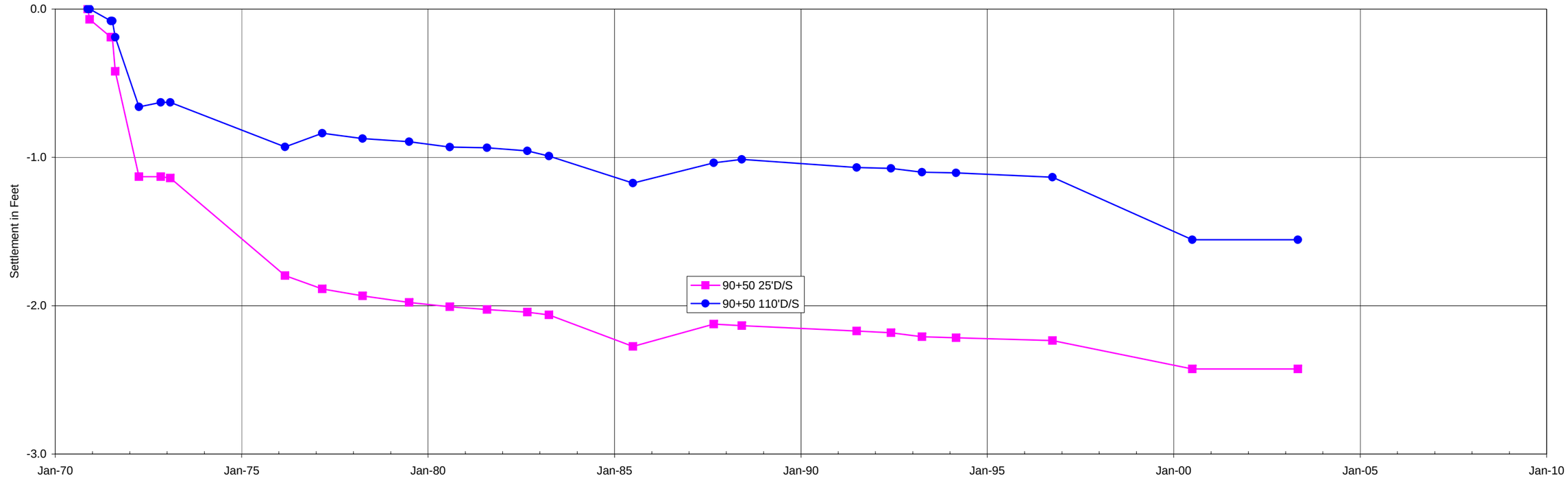
Re-Allocation Study Plate D-9

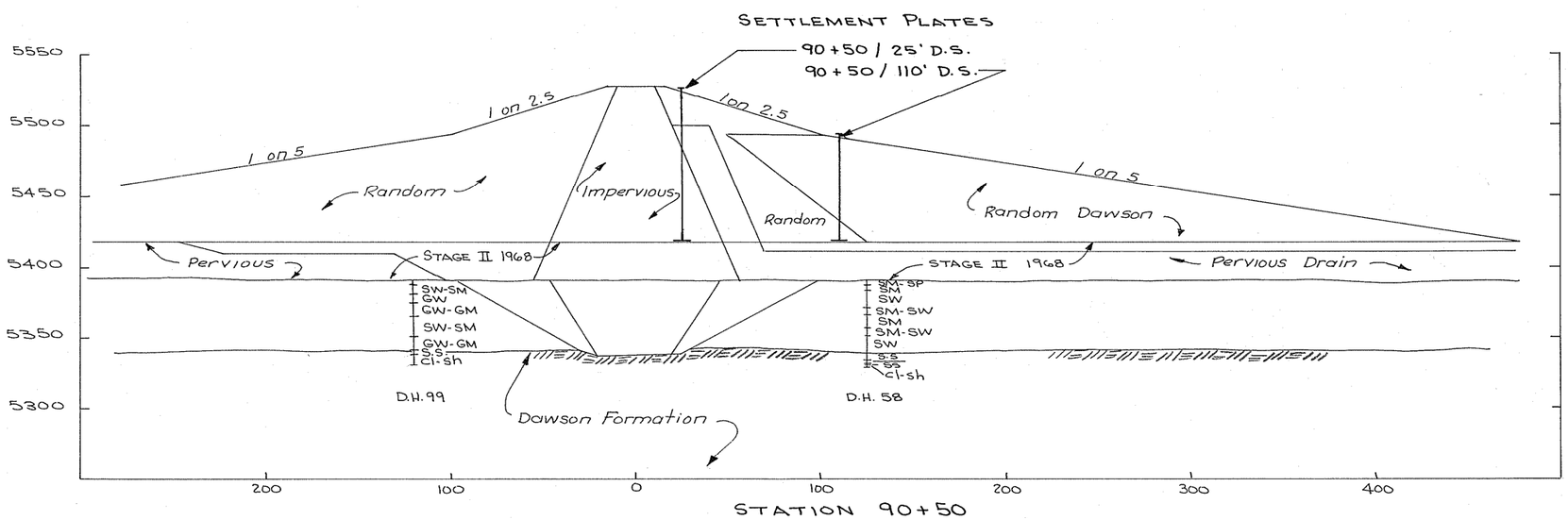




Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Settlement Gages - Sta. 70+00
Vertical Movement

Re-Allocation Study Plate D-10





Chatfield Dam and Lake, CO
Embankment & Foundation Movement
Settlement Gages - Sta. 90+00
Vertical Movement

Re-Allocation Study Plate D-11

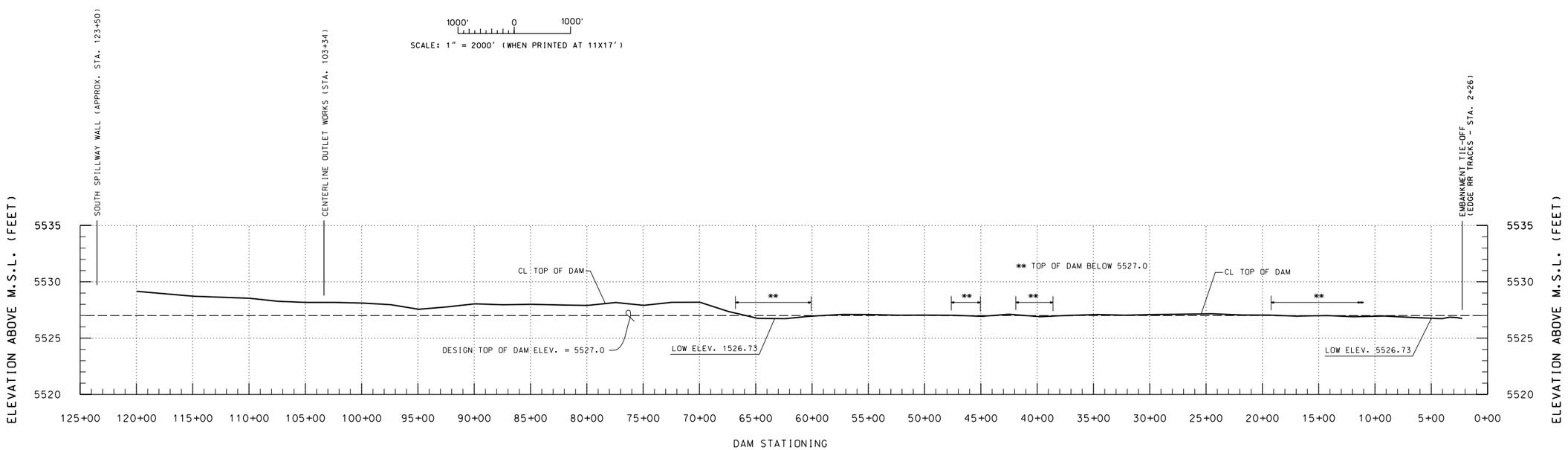
NOTES:

1. STATIONING SHOWN IS APPROXIMATELY EQUIVALENT TO DAM STATIONING. TOP OF DAM SURVEY WAS VISUALLY LINED UP WITH SEPT 2007 AERIAL PHOTOGRAPH OF DAM. STATIONING WAS ESTIMATED BASED ON CENTERLINE OF OUTLET WORKS.
2. TOP OF DAM SURVEY WAS CONDUCTED MAY 2007.
3. VERTICAL DATUM IS 1929 NGVD.
4. VERTICAL CONTROL FOR SURVEY WAS CONTROL POINT "WEST".

PLAN VIEW - CHATFIELD DAM

1000' 0 1000'

SCALE: 1" = 2000' (WHEN PRINTED AT 11X17')



TOP OF DAM PROFILE

500' 0 500'

5' 0 5'

HOR. SCALE: 1" = 1000' (WHEN PRINTED AT 11X17')
VER. SCALE: 1" = 10' (WHEN PRINTED AT 11X17')

US ARMY CORPS OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.	MARK	DESCRIPTION	DATE	APPR.

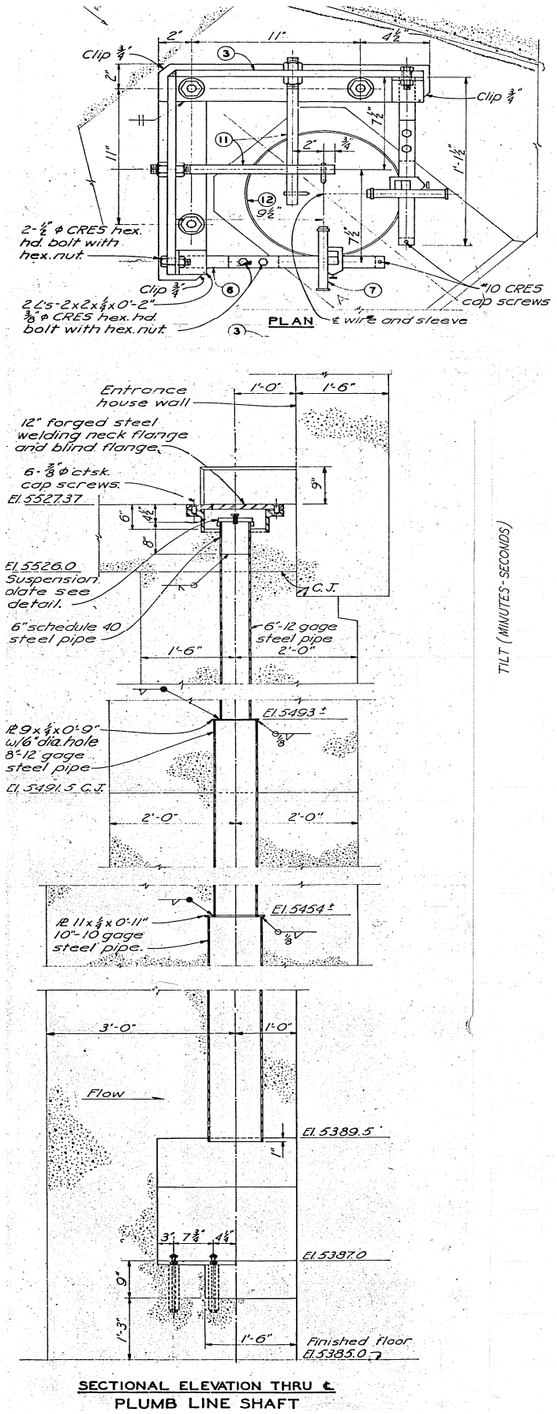
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
OMAHA DISTRICT

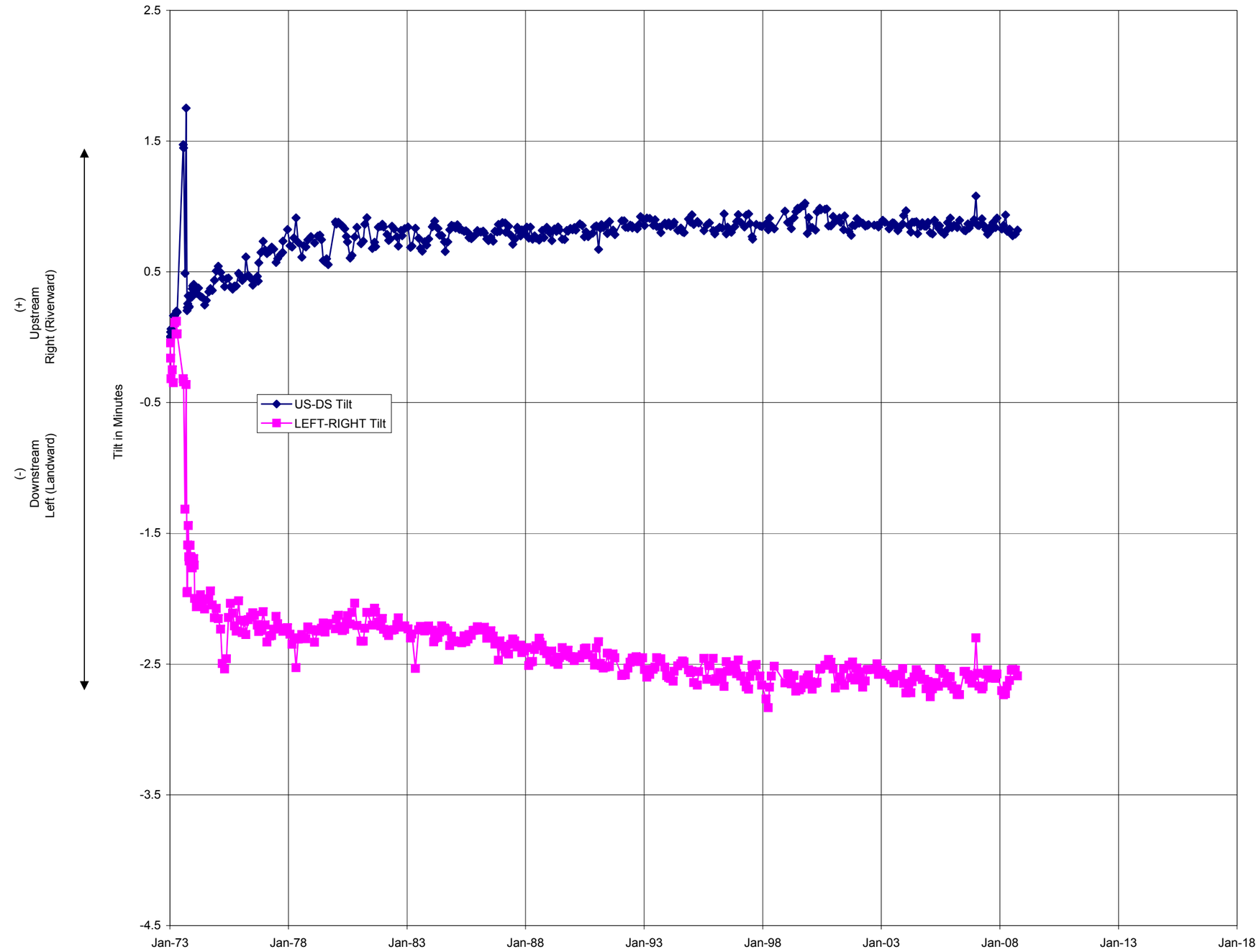
DESIGNED BY: | DATE: 20 OCT 2008
DWN BY: B.J.L. | CKD BY: M.T.K. | SOLICITATION NO.:
SUBMITTED BY: | CONTRACT NO.:
FILE NAME: | FILE NUMBER:
SIZE: | PLOT SCALE: | PLOT DATE:

CHATFIELD DAM AND LAKE, COLORADO

TOP OF DAM SURVEY
MAY 2007

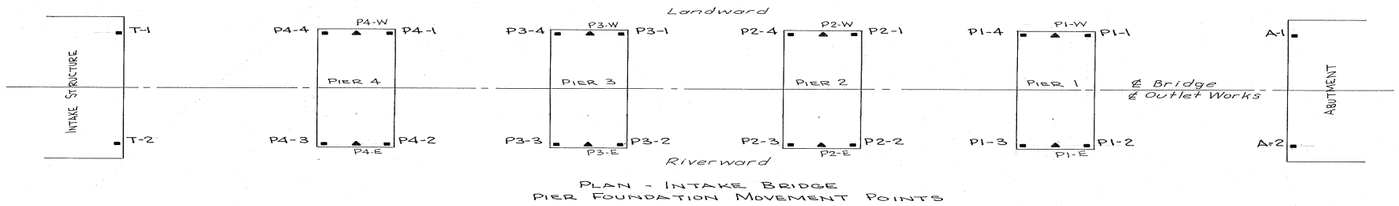
SHEET IDENTIFICATION NUMBER
D-12



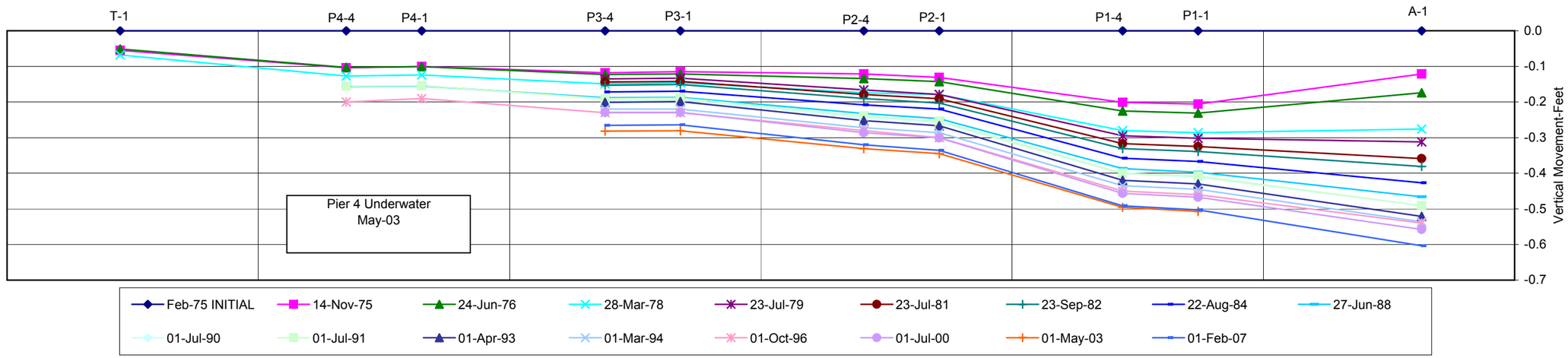


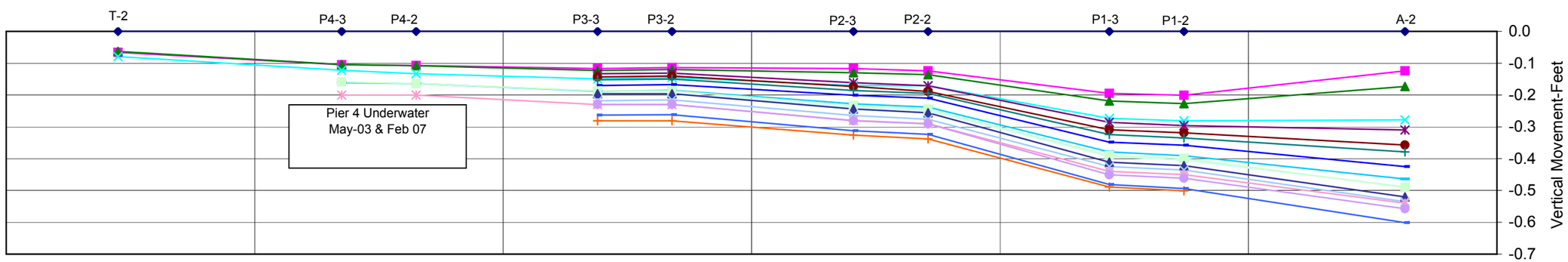
Chatfield Dam and Lake, Colorado
Outlet Works - Intake Structure
Plumbline Tilt

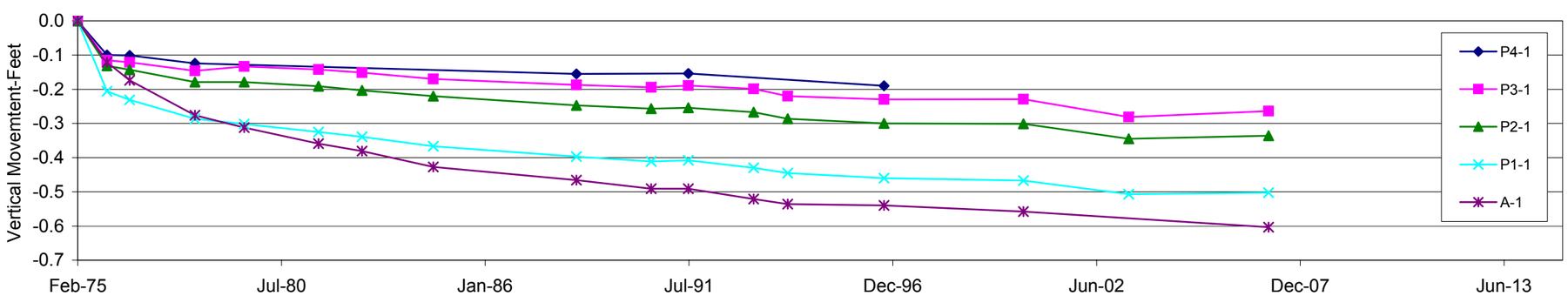
Re-Allocation Study Plate D-13



Plan - Intake Bridge
Pier Foundation Movement Points

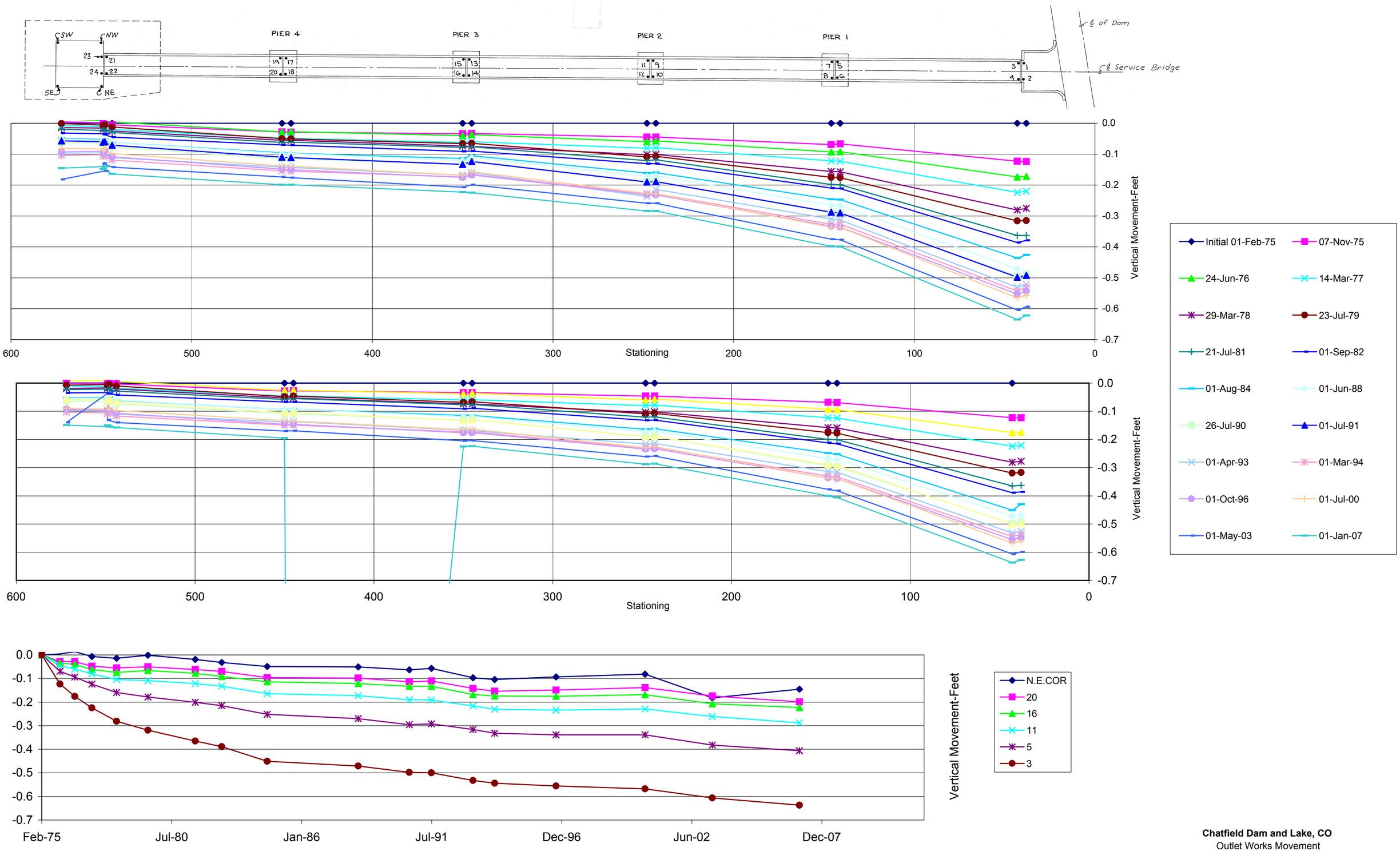






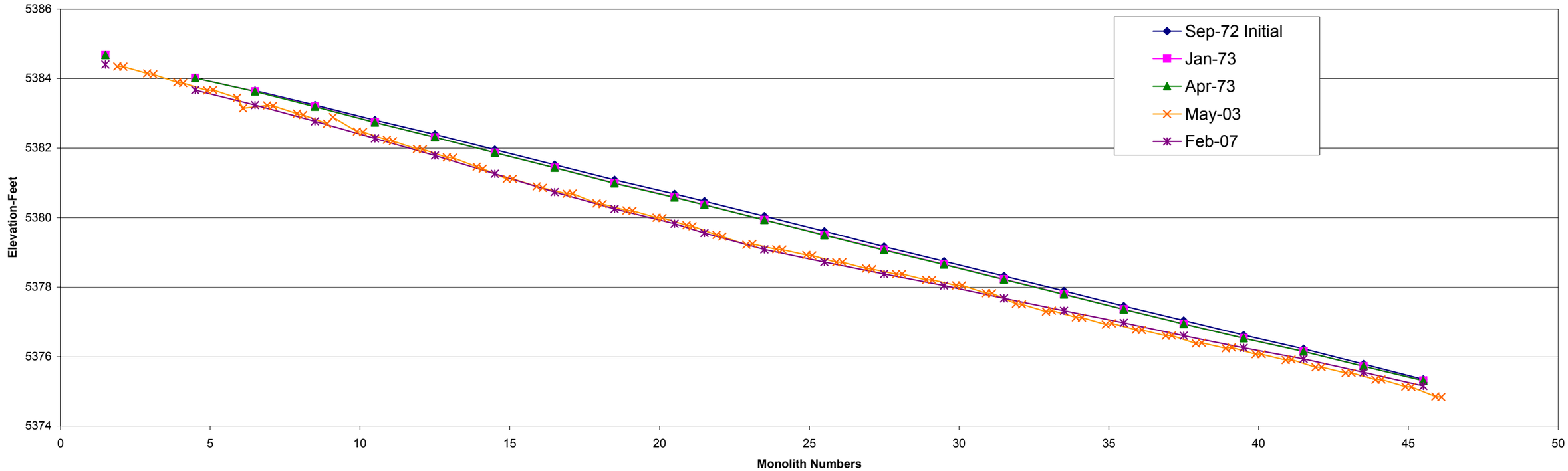
Chatfield Dam and Lake, CO
Outlet Works Movement
Intake Bridge Piers & Tower
Verical Movement

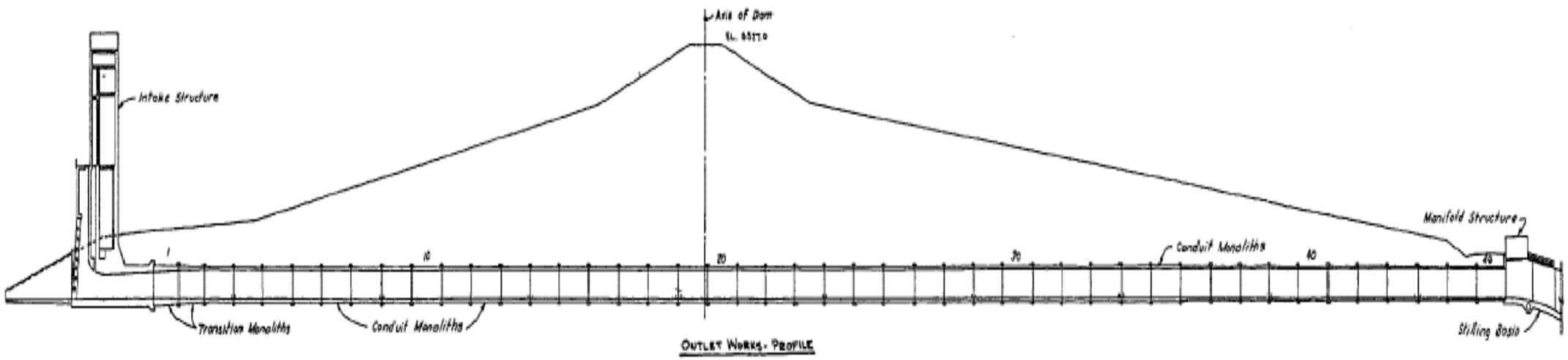
Re-Allocation Study Plate D-14



Chatfield Dam and Lake, CO
Outlet Works Movement
Intake Bridge Deck & Tower Vertical Movement

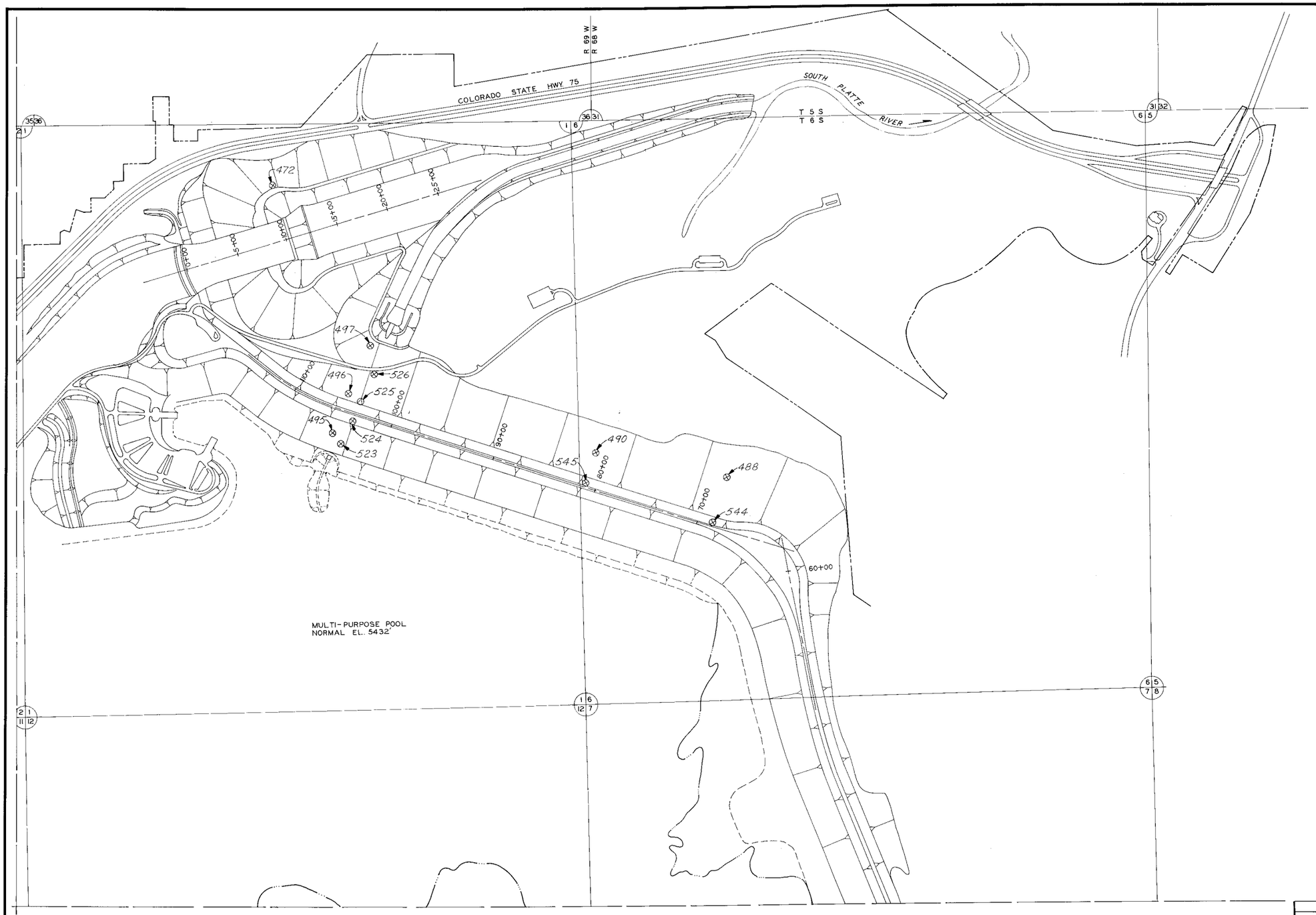
Re-Allocation Study Plate D-15





Chatfield Dam
Outlet Works - Wet Conduit
Vertical Movement Profile

Re-Allocation Study Plate D-16



INCLINOMETERS		
EMBANKMENT		
NO.	STATION	RANGE
544	68 + 80	17' D. S.
488	68 + 80	500' D. S.
545	81 + 20	17' D. S.
490	81 + 20	350' D. S.
495	104 + 78.1	232' U. S.
496	104 + 53.9	167.2' D. S.
497	104 + 21.2	667.5 D. S.
OUTLET WORKS		
523	-2 + 92 (U. S.)	9.5' Left
524	-0 + 68 (U. S.)	9.5' Left
525	1 + 00 (D. S.)	9.5' Left
526	4 + 36 (D. S.)	9.5' Left
SPILLWAY SLOPE		
472	10 + 60	500' Left

SCALE: 1 INCH = 400 FEET
400' 0 400'

LEGEND:
⊕ Inclinometers

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

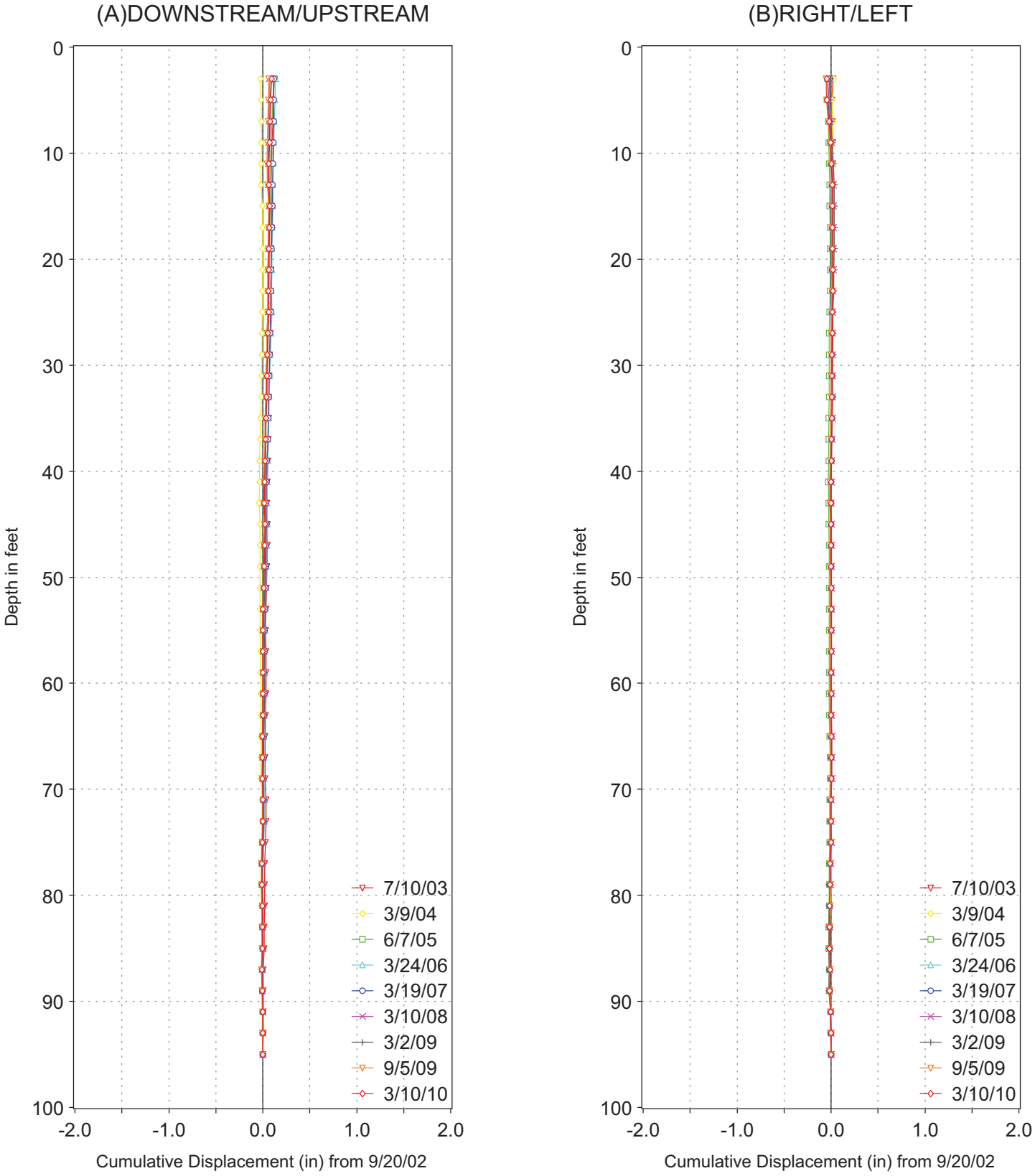
DESIGNED BY:
DRAWN BY: J. L. C.
CHECKED BY:
SUBMITTED BY:
CHIEF SECTION
RECOMMENDED:
CHIEF DESIGN BRANCH
APPROVED:
COL. C. E. DISTRICT ENGINEER

SOUTH PLATTE RIVER
CHATFIELD LAKE, COLORADO
EMBANKMENT AND SPILLWAY
INCLINOMETERS
LOCATION PLAN

APPROVED: CHIEF ENGINEERING DIVISION
DATE:
SCALE: AS SHOWN
SPEC. NO. DACA45
DRAWING NUMBER
SHEET 1

THIS PLAN ACCOMPANIES CONTRACT No. DACA45 MODIFICATION No.

U. S. GOVERNMENT PRINTING OFFICE: 1976-646-144



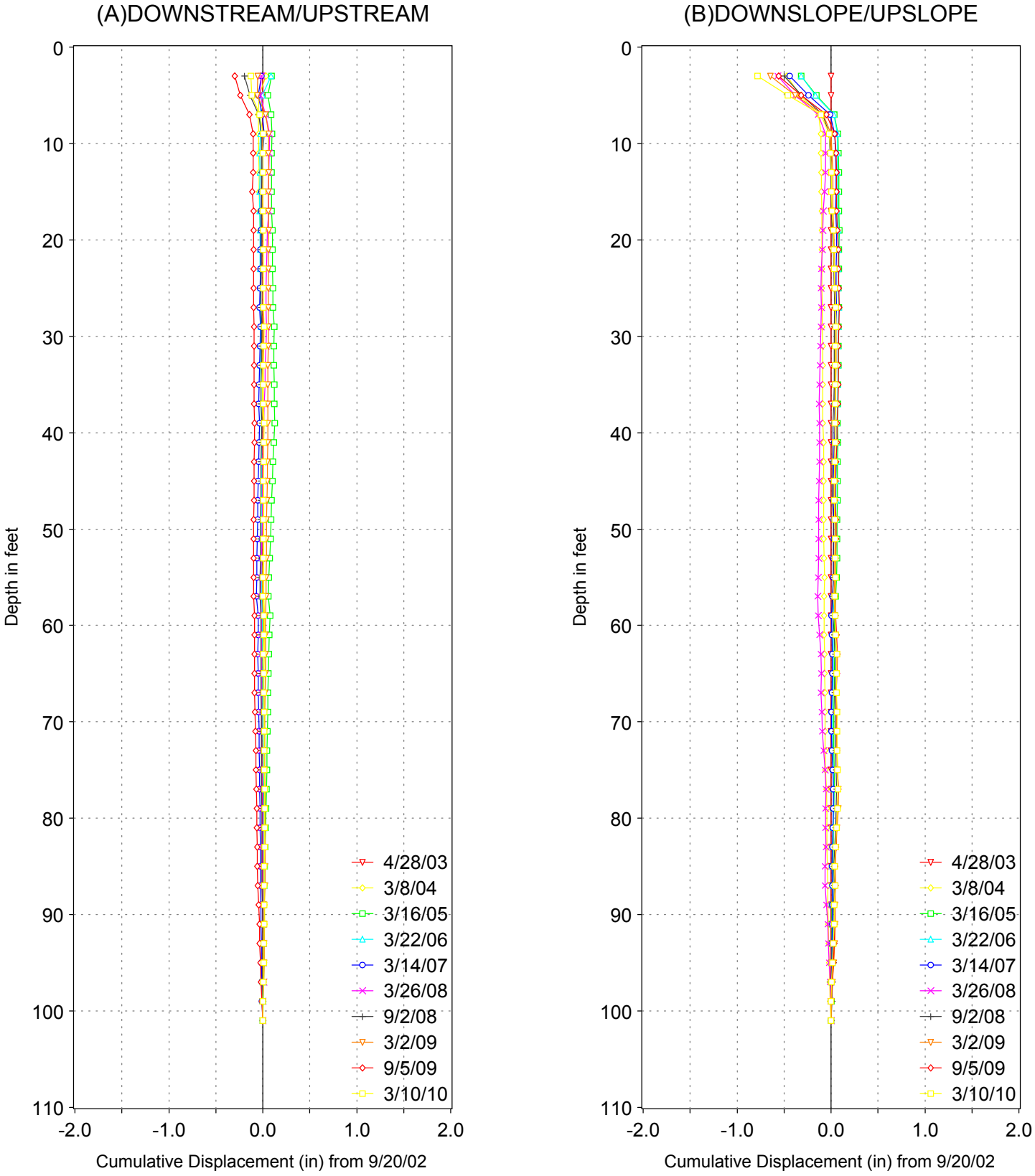
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 497, Sta. 104+21, 668' DS

Cumulative Displacement 2002 - Present

Reallocation Study **Plate D-18**



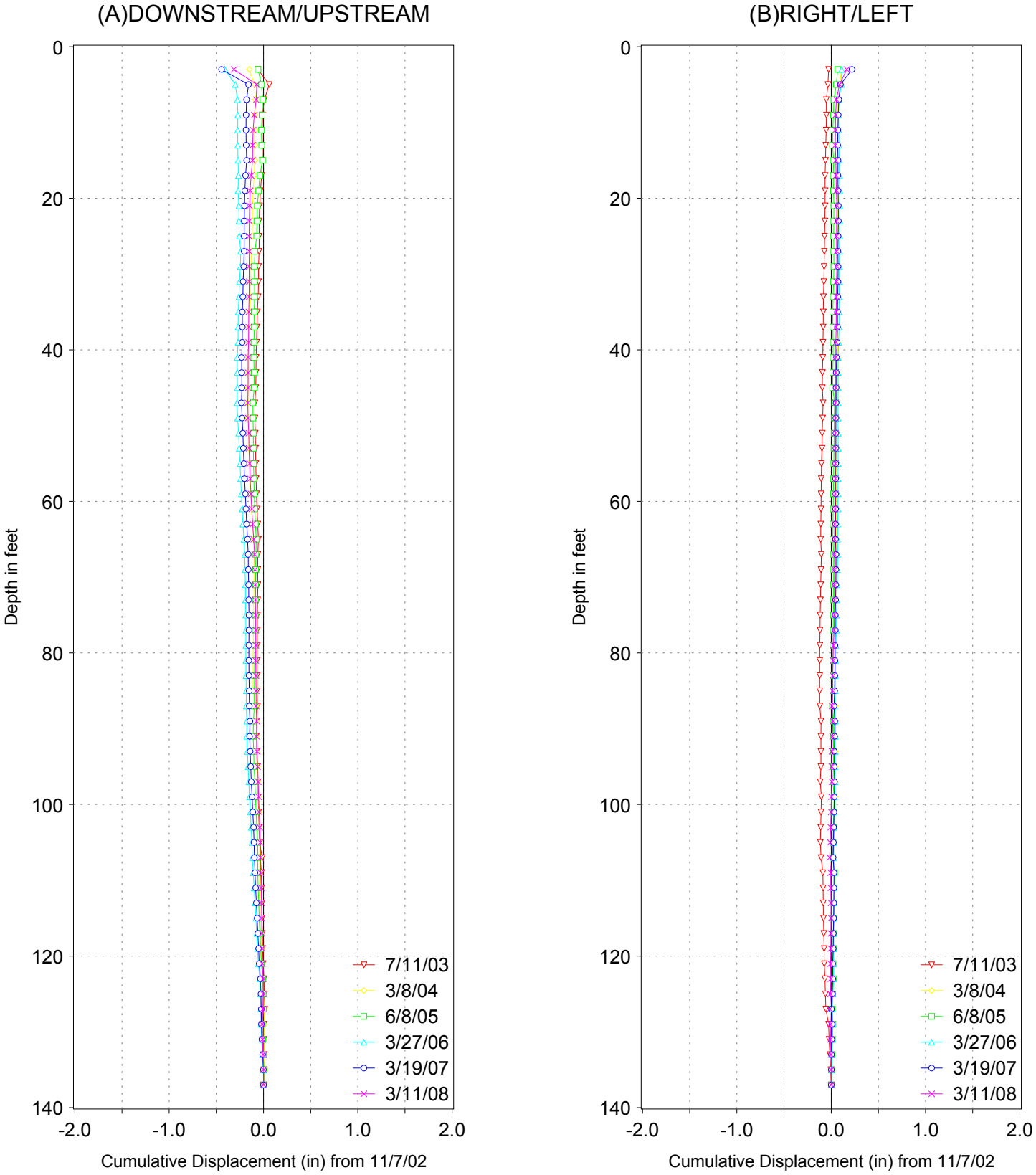
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 472, Spillway Sta. 10+60, 500' Left

Cumulative Displacement 2002-Present

Reallocation Study **Plate D-19**



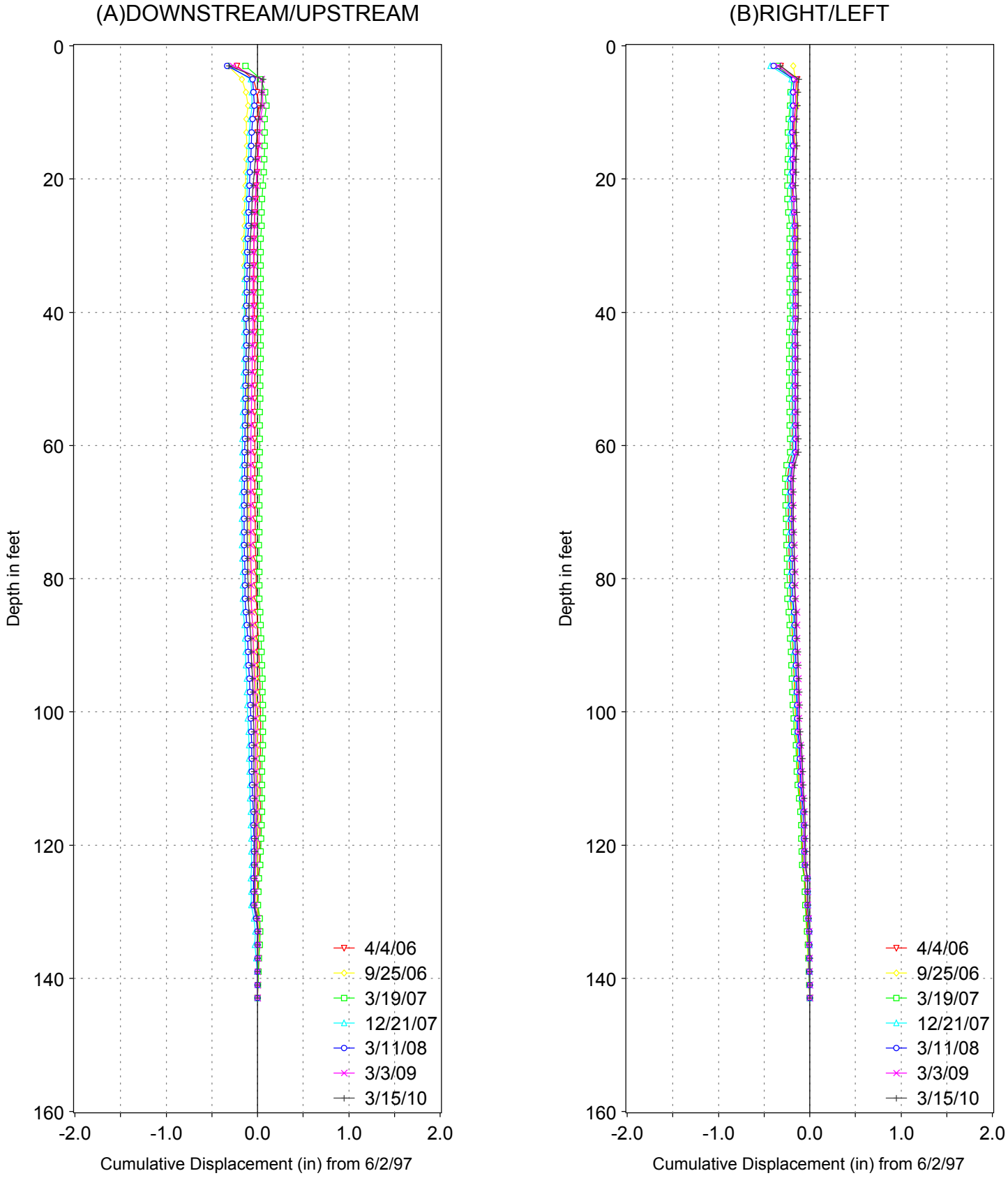
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 488, Sta. 68+90, 500' DS

Cumulative Displacement 2002 - Present

Realloction Study **Plate D-20**



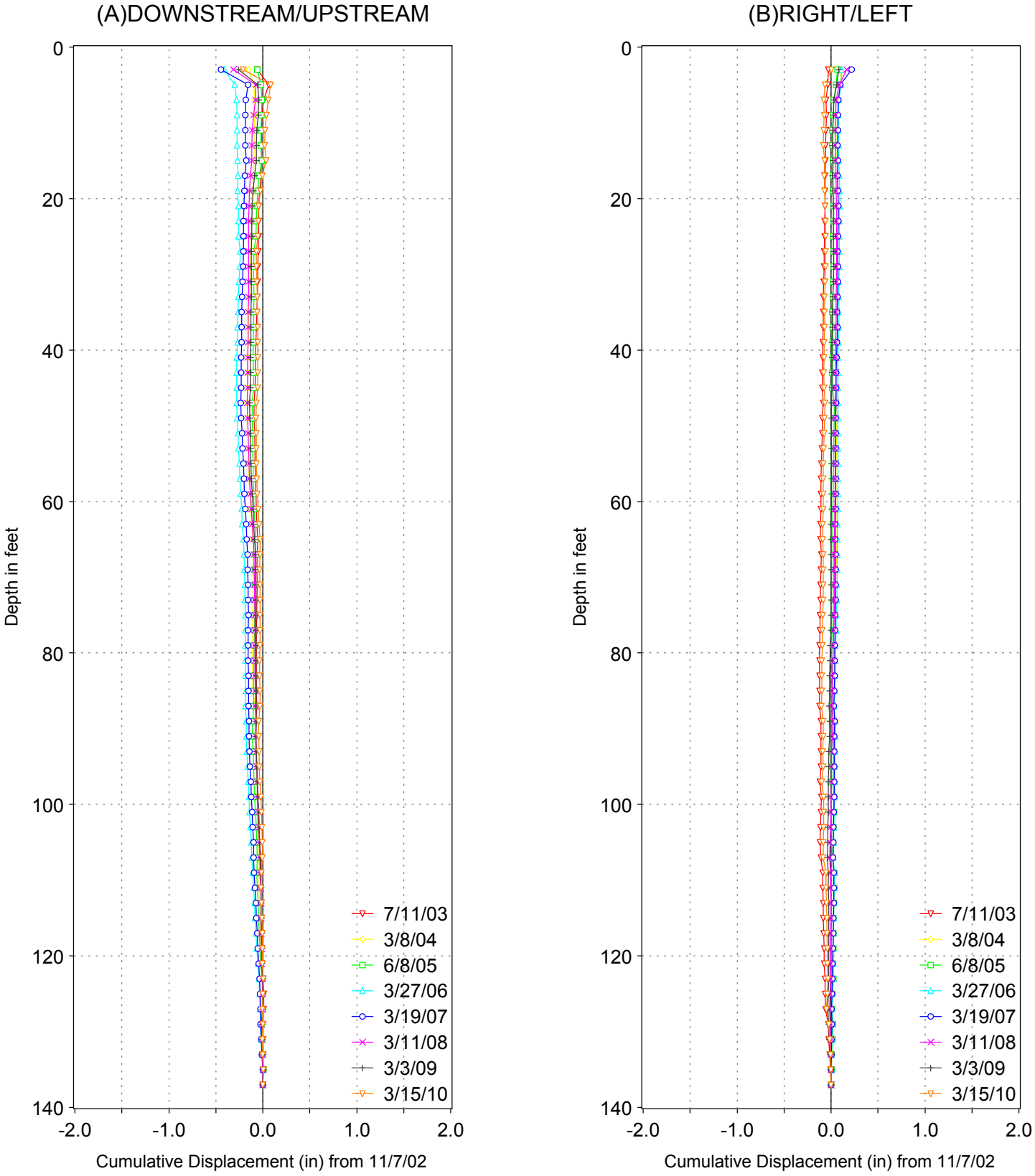
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 490, Sta. 81+20, 350' DS

Cumulative Displacement 97 - Present

Reallocation Study **Plate D-21**



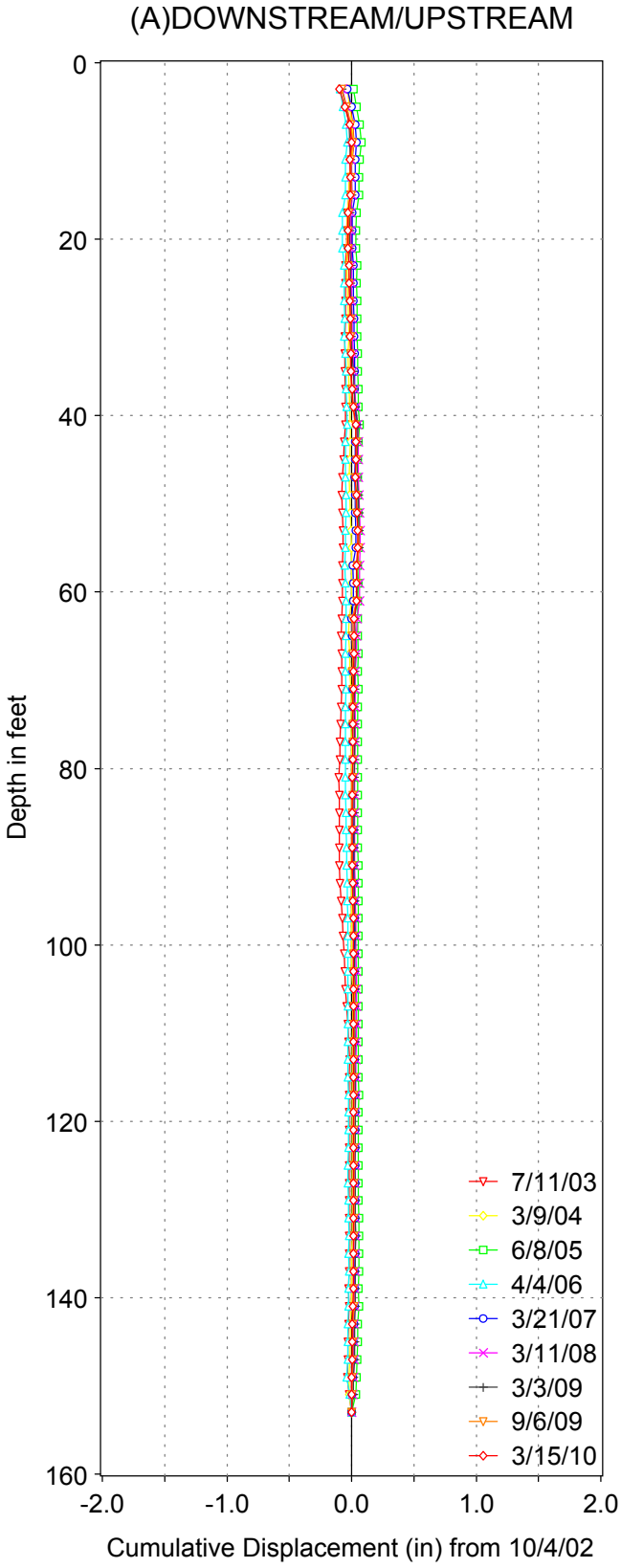
US Army Corps of Engineers®

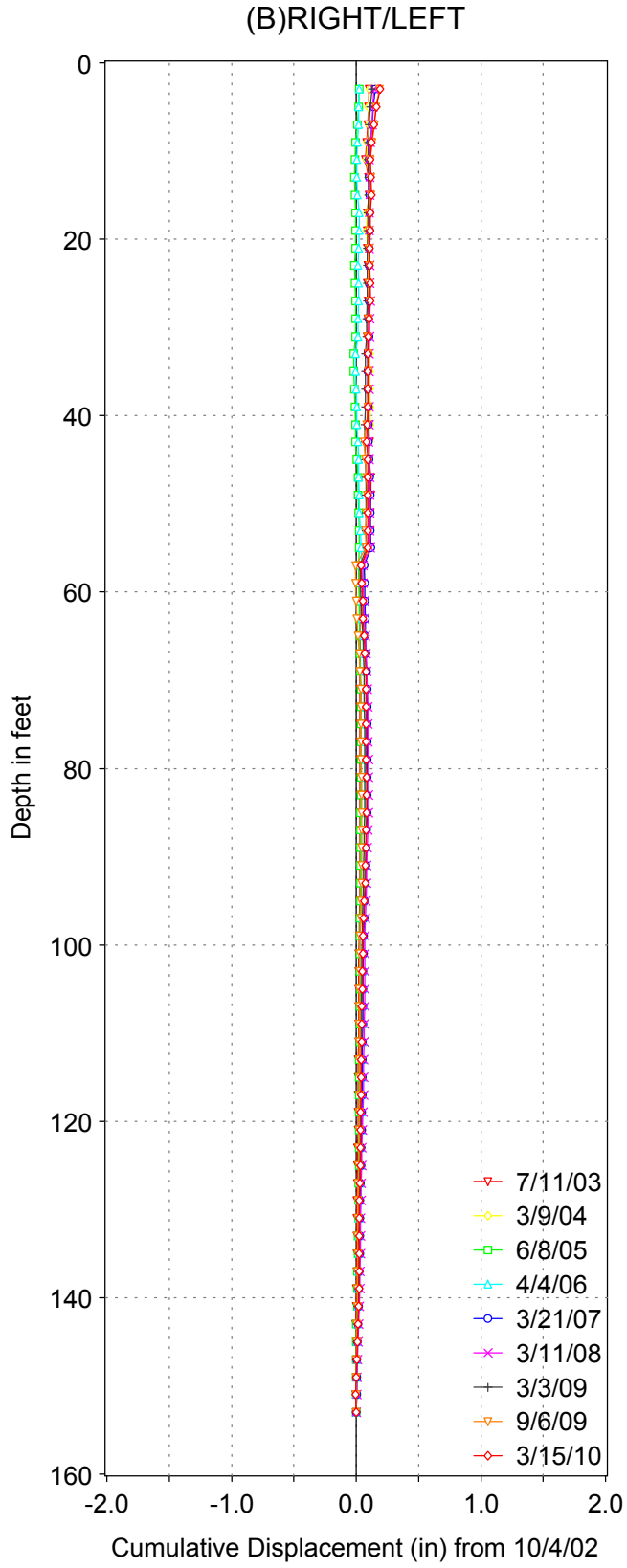
Chatfield Dam and Lake, CO

Inclinometer 488, Sta. 68+90, 500' DS

Cumulative Displacement 2002 - Present

Reallocation Study **Plate D-22**





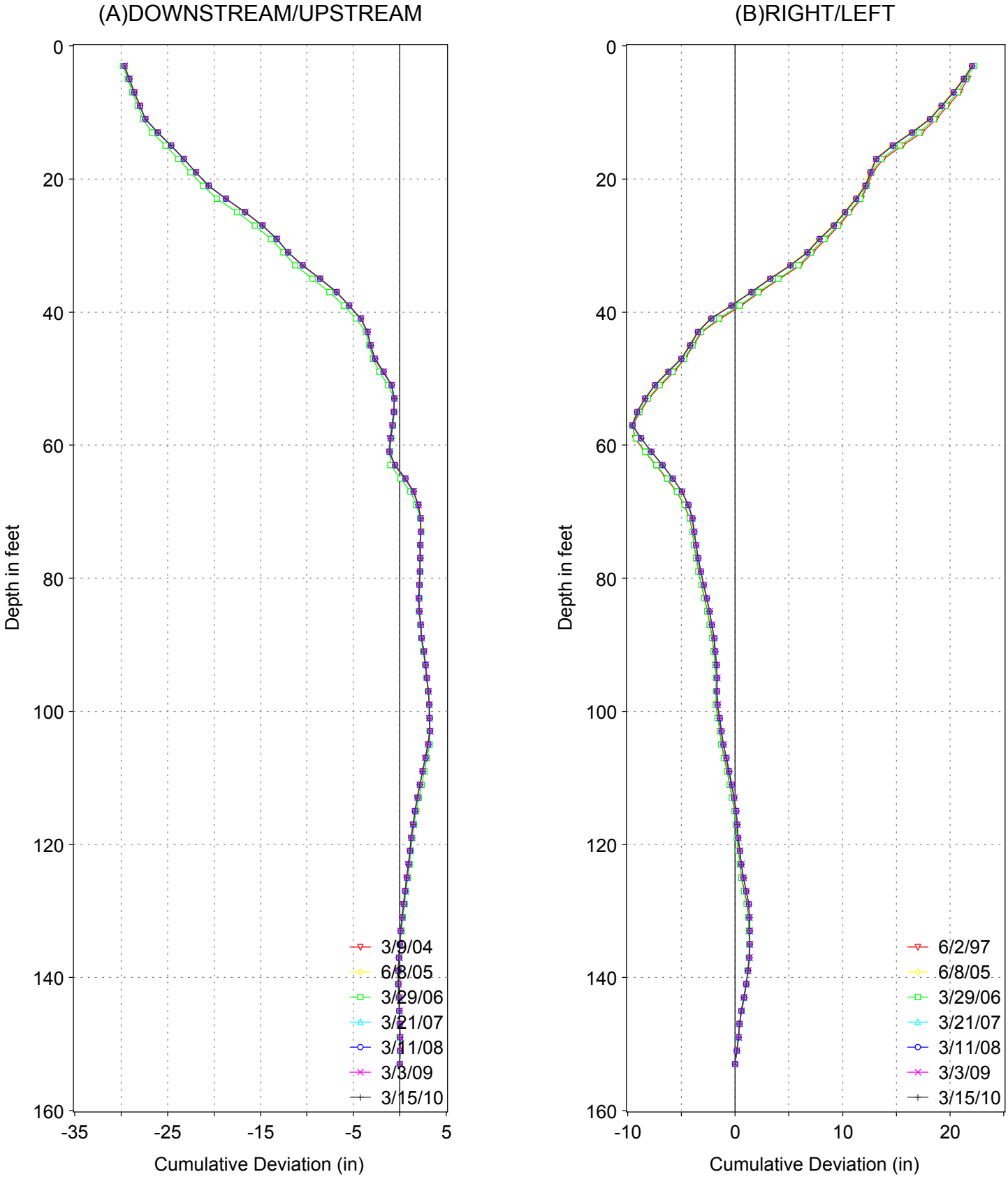
US Army Corps of Engineers®

Chatfield Dam and Dam, CO

Inclinometer 496, Sta. 104+54, 167' DS

Cumulative Displacement 2002 - Present

Reallocation Study **Plate D-23**



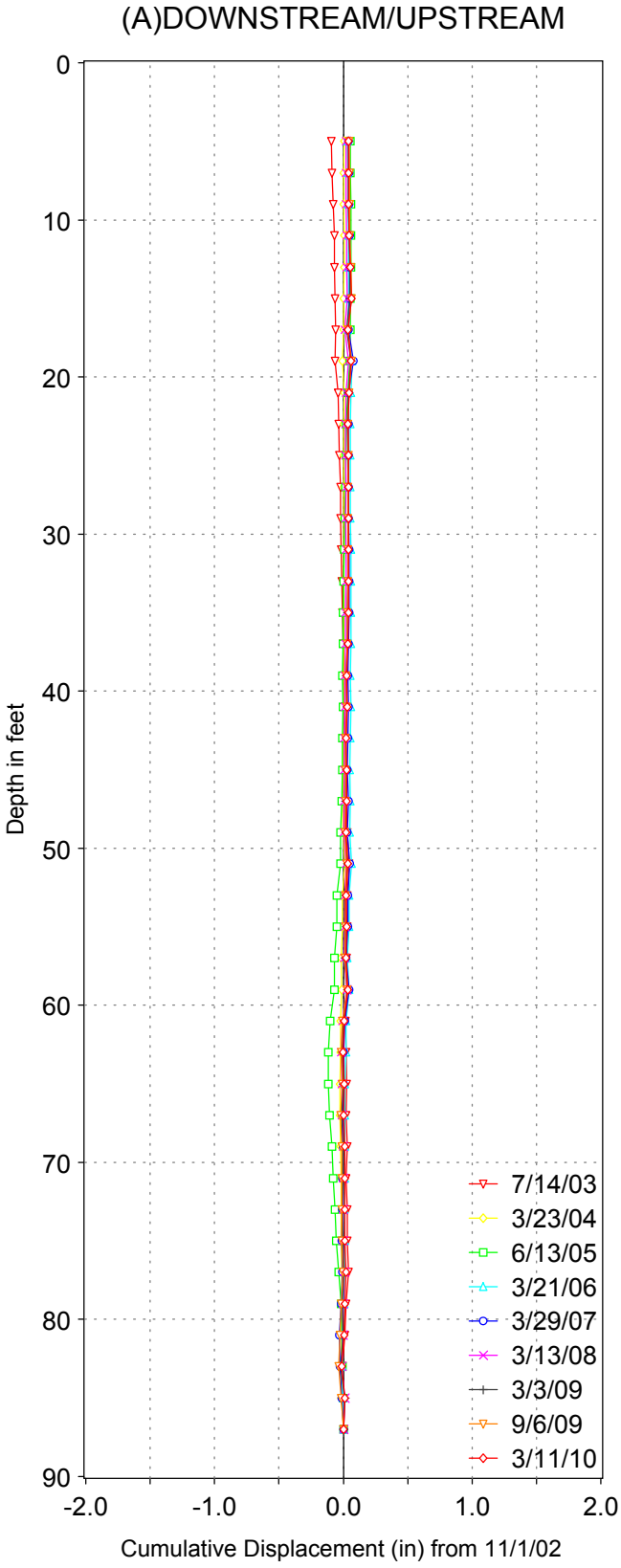
US Army Corps of Engineers®

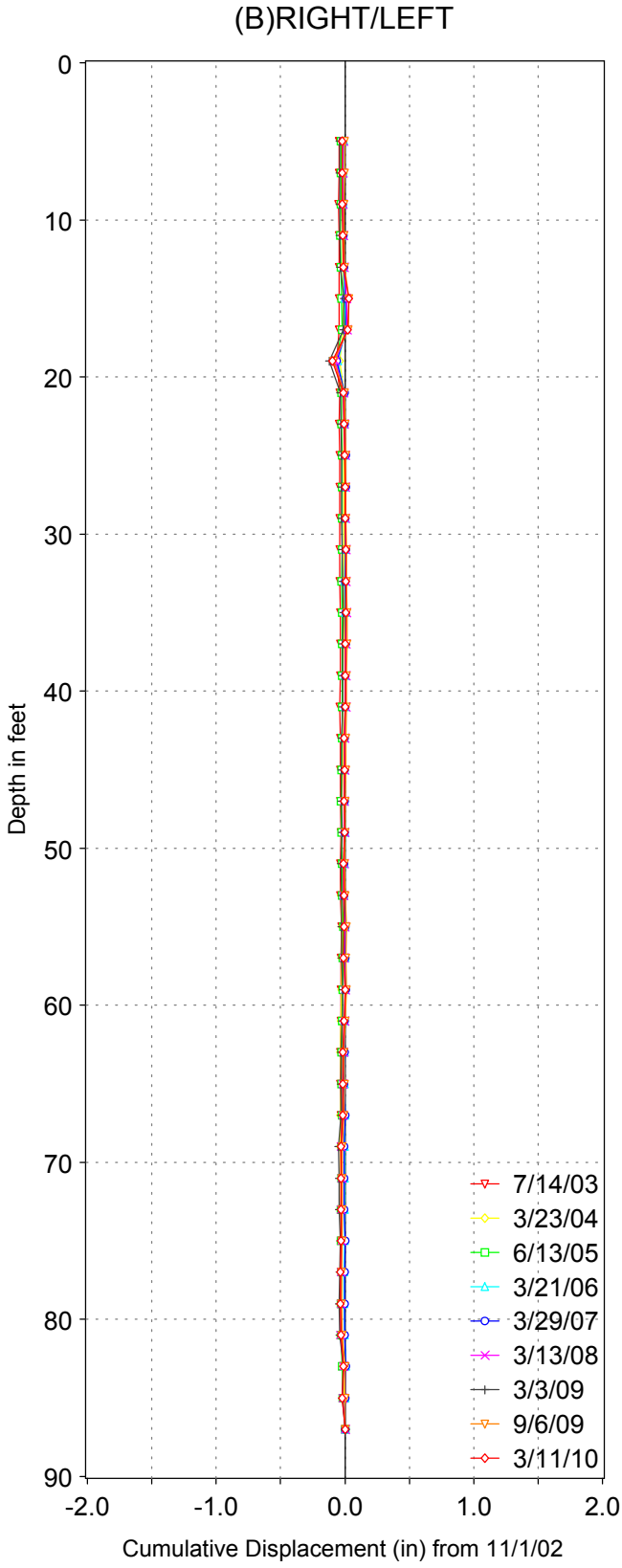
Chatfield Dam and Lake, CO

Inclinometer 496, Sta. 104+54, 167' DS

Cumulative Deviation

Reallocation Study **Plate D-23A**





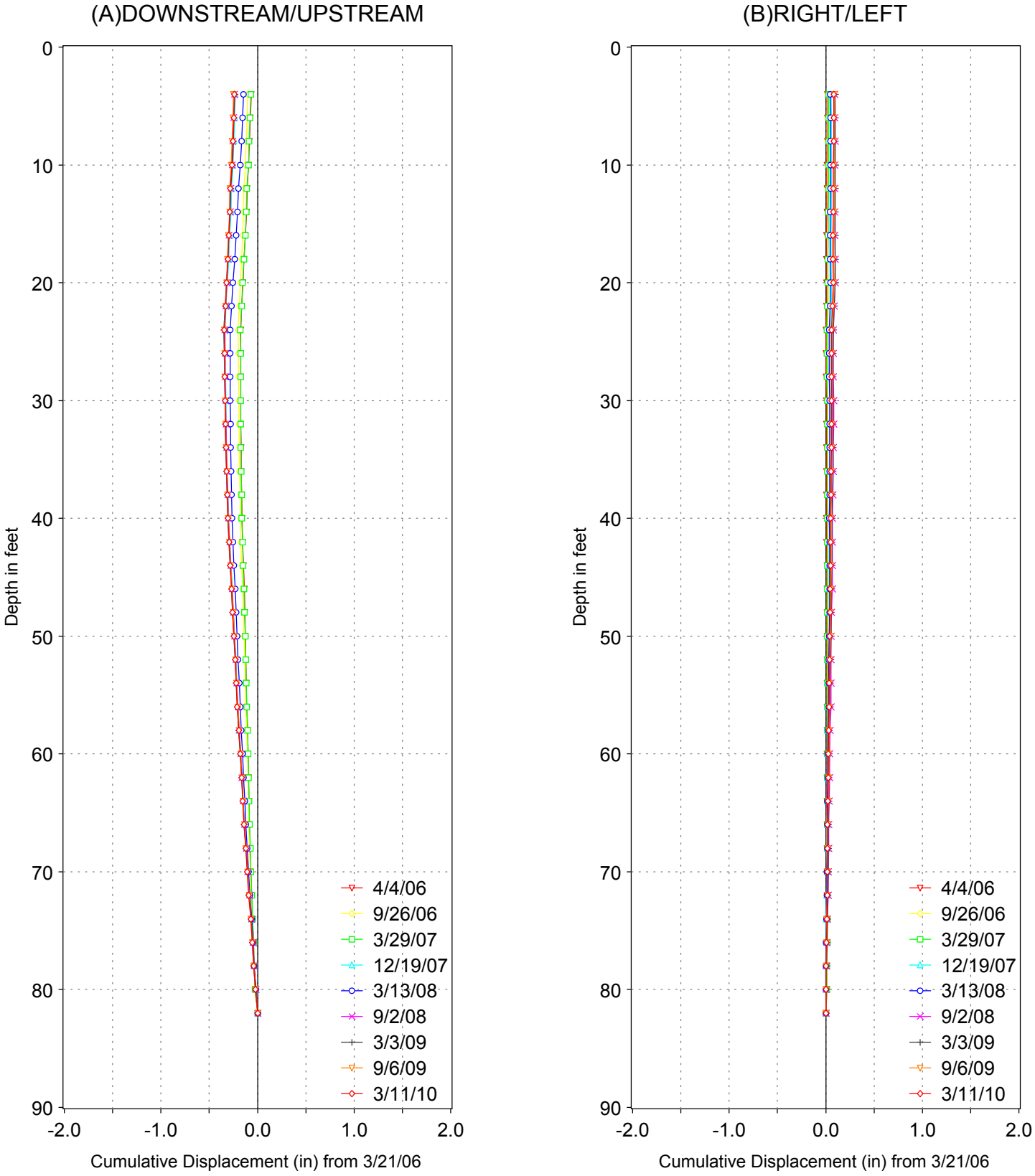
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometers 523, Outlet Works Sta. 2+92, 9.5' LEFT

Cumulative Displacement 2002 - Present

Realloction Study **Plate D-24**



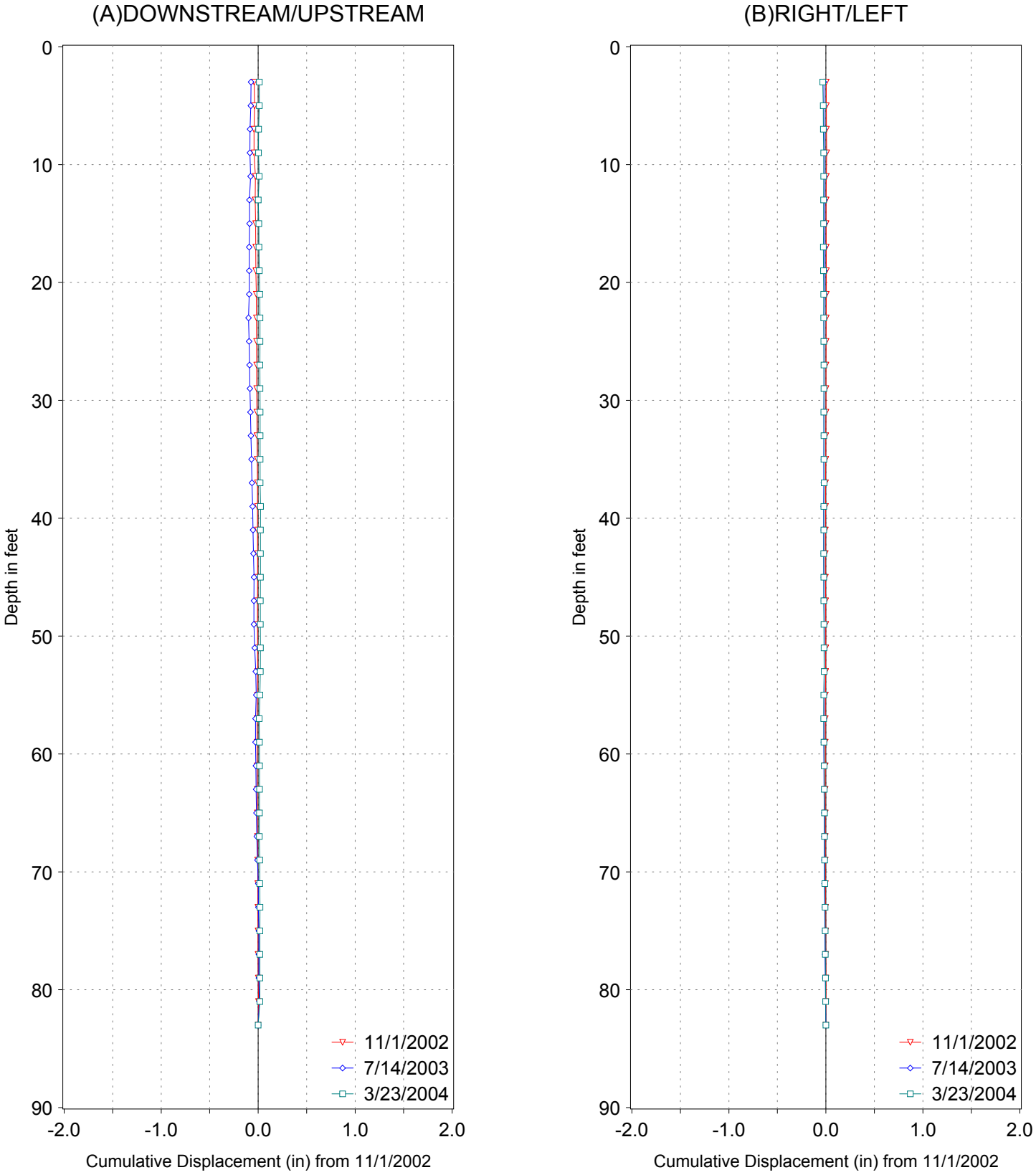
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 524, Outlet Works Sta. 0+68, 9.5' Left

Cumulative Displacement 2006 - Present

Reallocation Study **Plate B-25**



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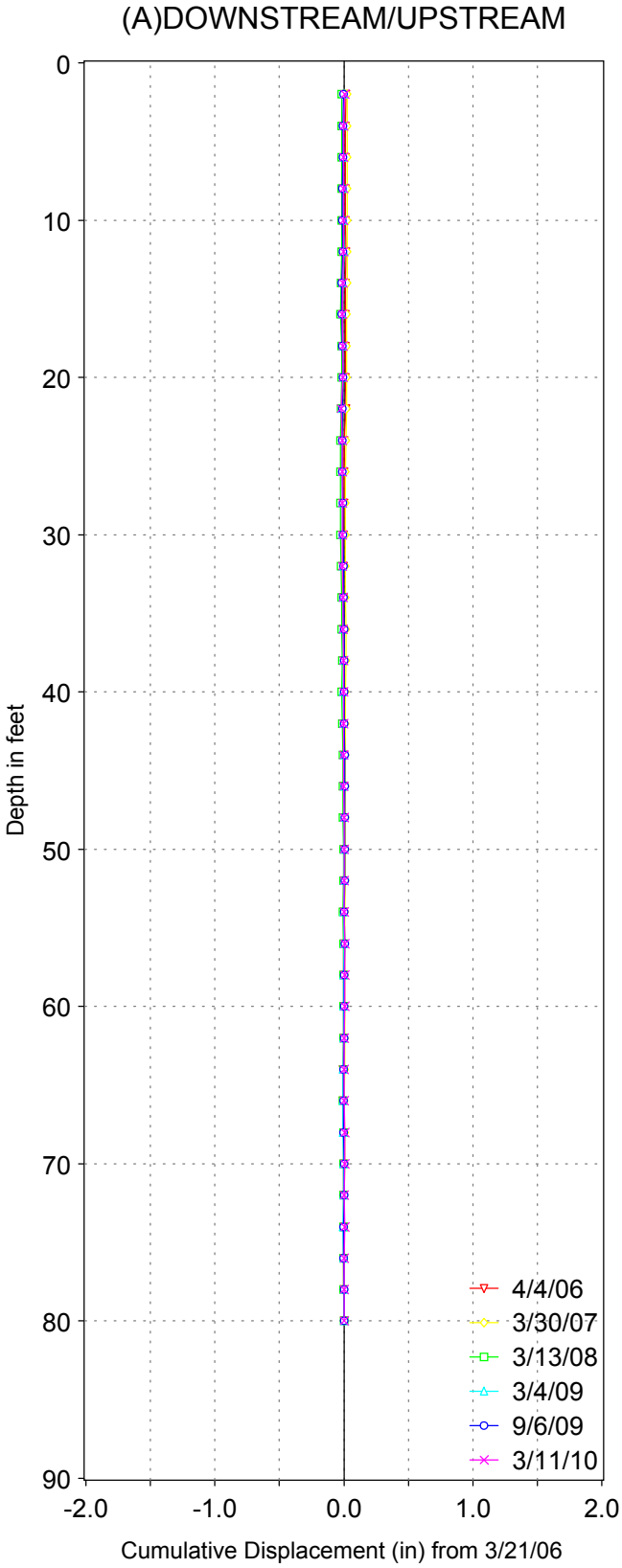
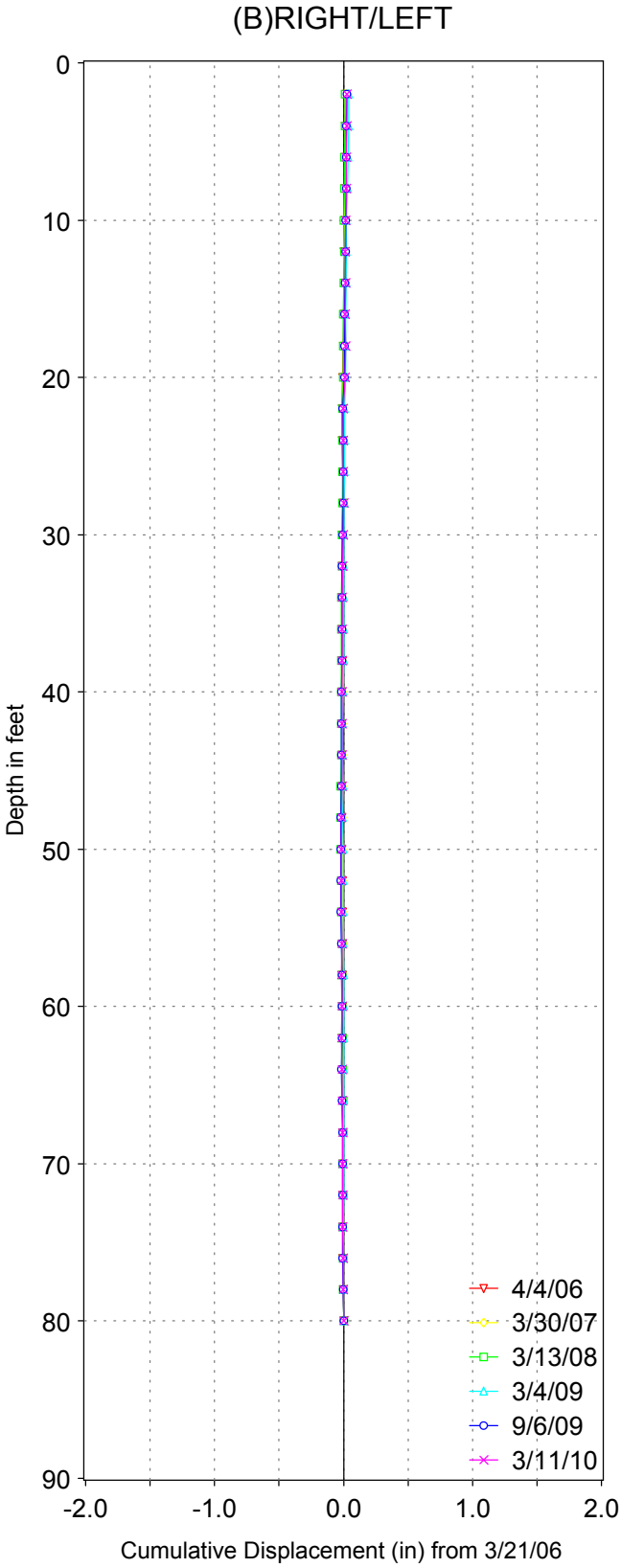
Chatfield Dam and Lake, CO

Inclinometer 525, Outlet Works Sta. 1+00, 9.5' Left

Cumulative Displacement 2002 - Present

Reallocation Study **Plate D-26**





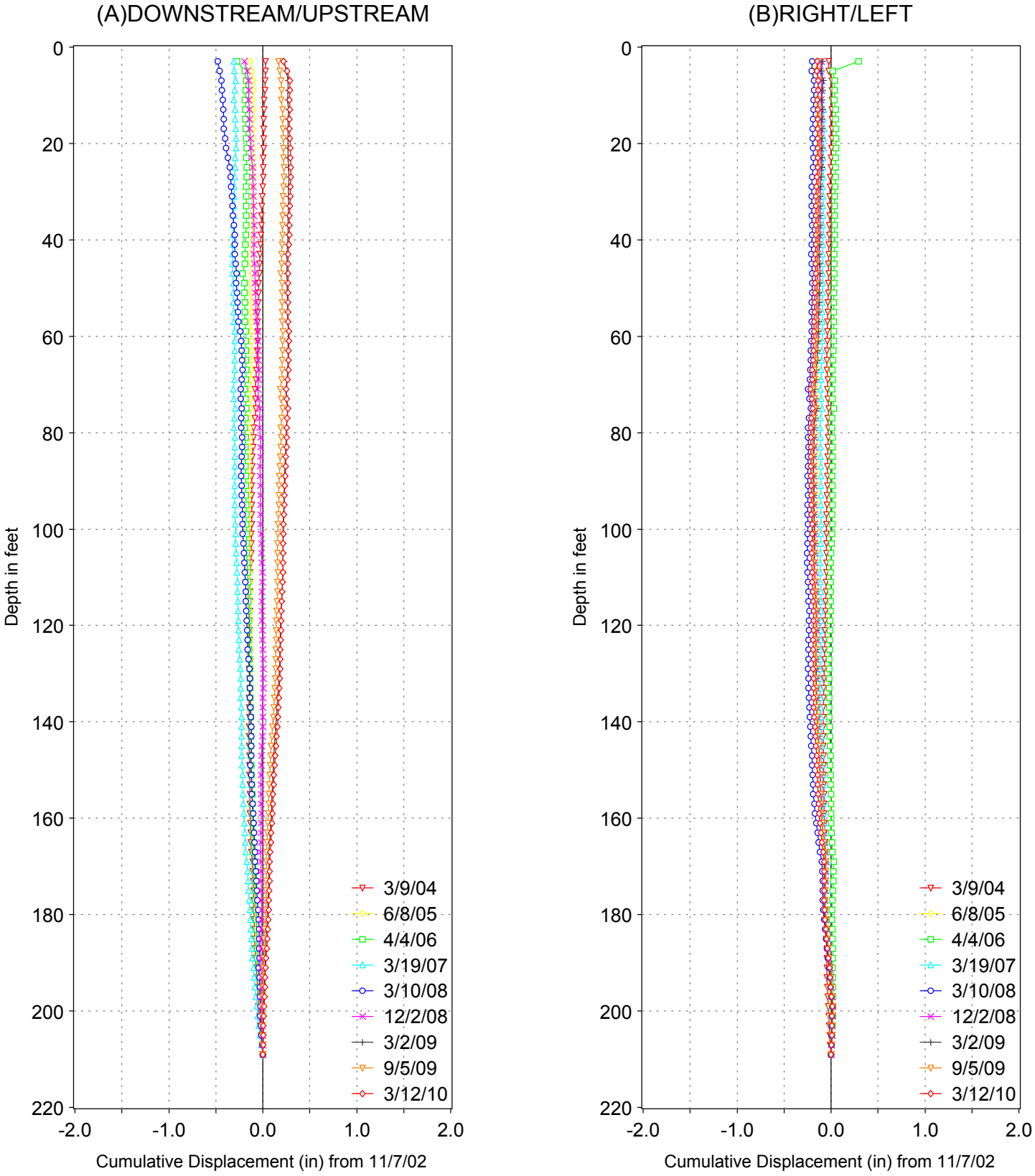
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 526, Outlet Works Sta. 4+36, 9.5' Left

Cumulative Displacement 2006 - Present

Reallocation Study **Plate D-27**



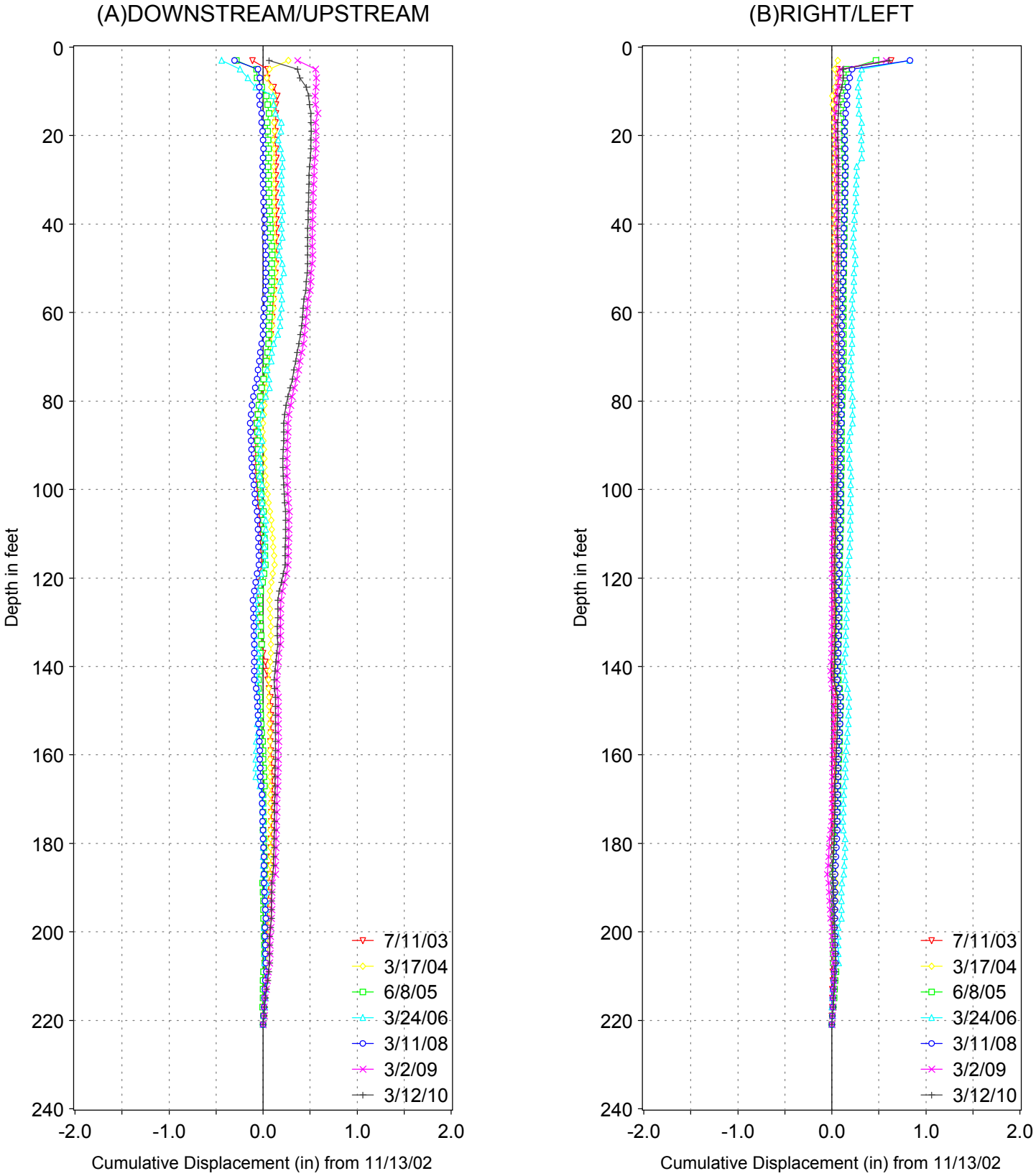
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 544, Sta. 68+80, 17' D.S.

Cumulative Displacement 2002 - Present

Reallocation Study **Plate D-28**



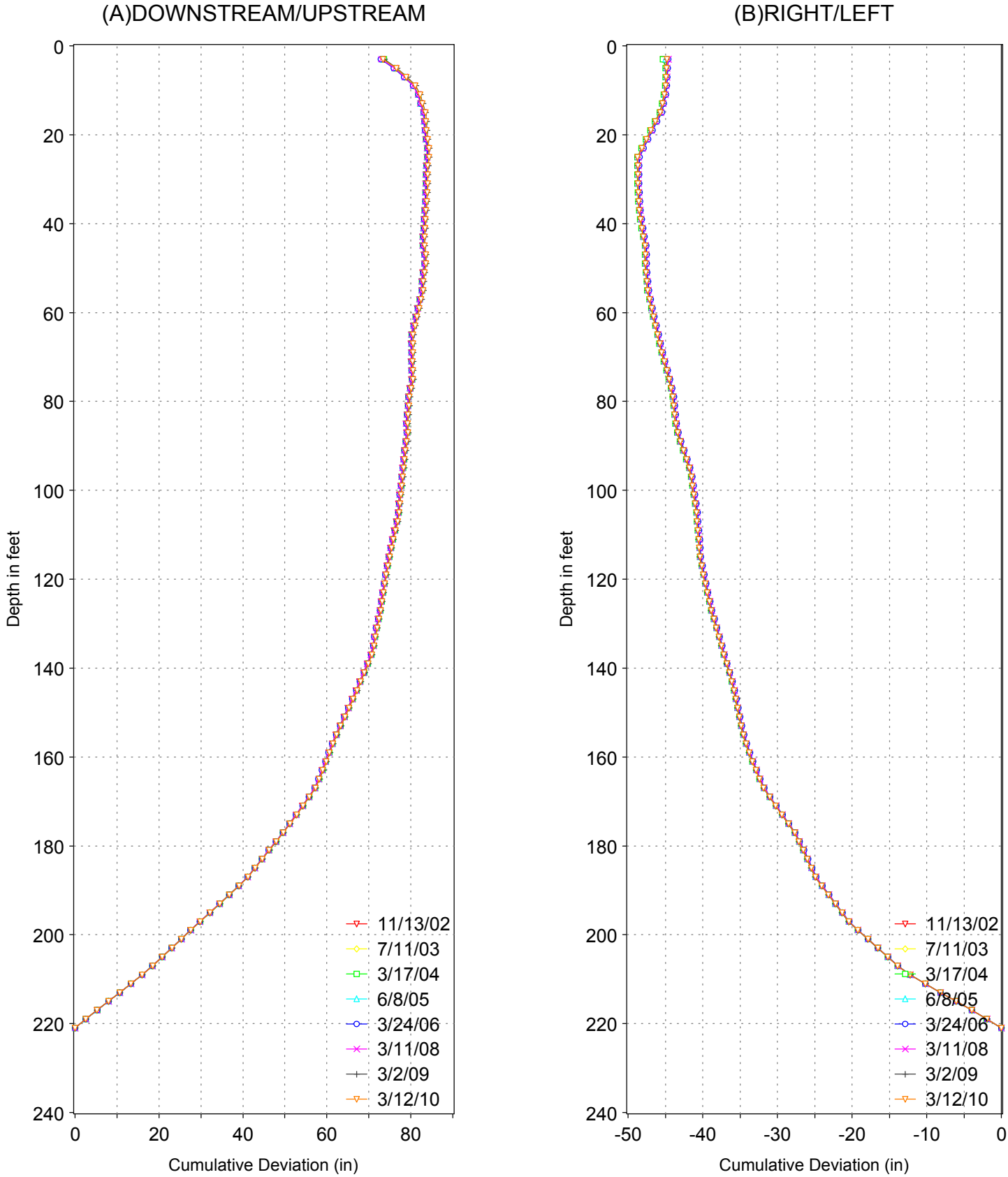
US Army Corps of Engineers®

Chatfield Dam and Lake, CO

Inclinometer 545, Sta. 81+10, 17' DS

Cumulative Displacement 2002 - Present

Reallocation Study **Plate D-29**



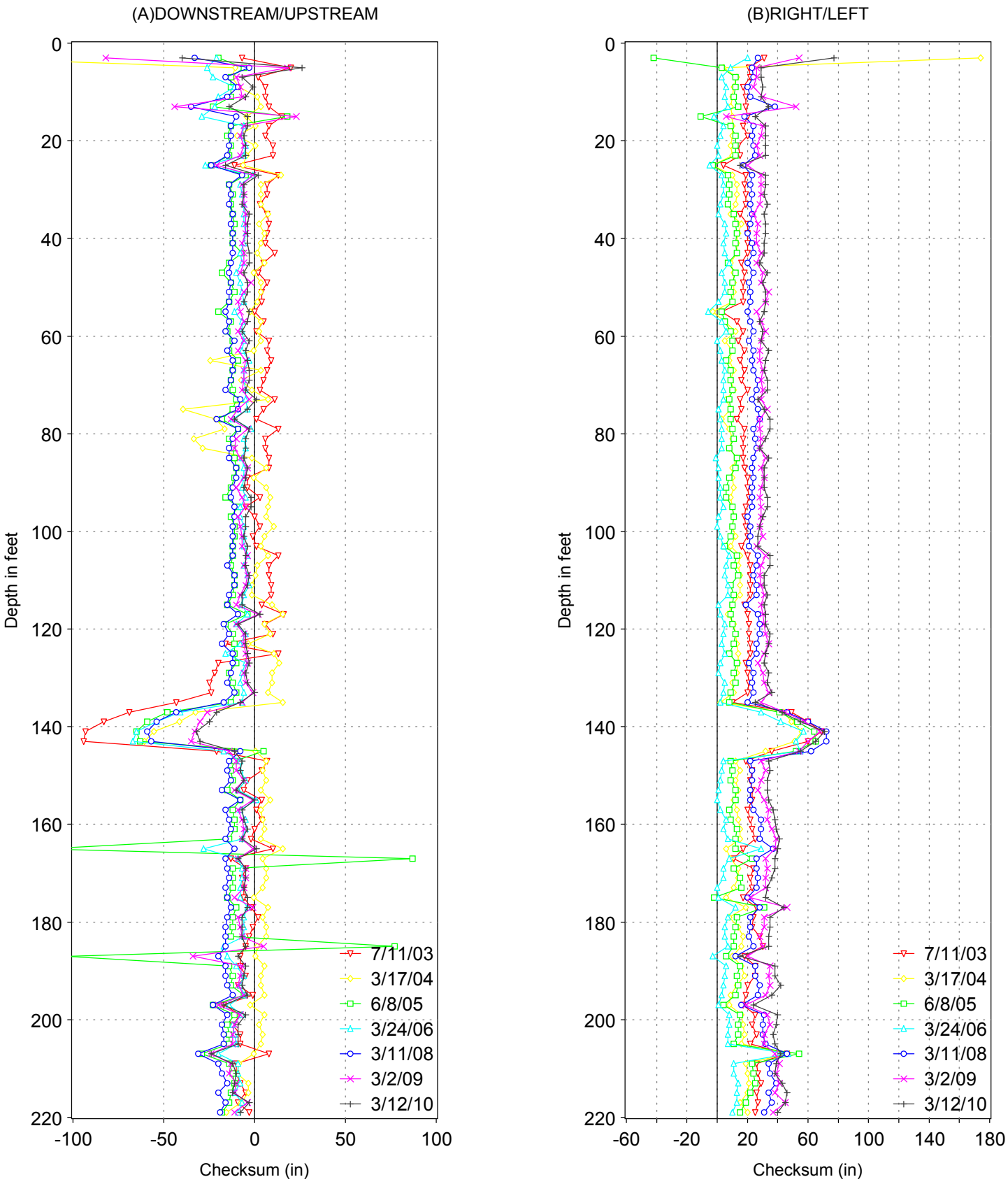
US Army Corps of Engineers®

Chatfield Dam and Lake, Co

Inclinometer 545, Embankment Sta. 81+10, 17' DS

Cumulative Deviation 2002 - Present

Reallocation Study **Plate D-30**



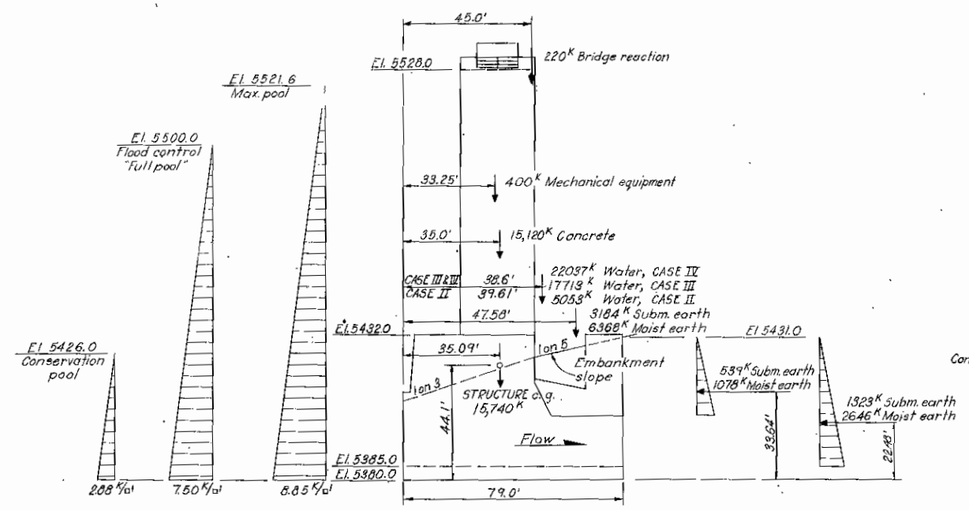
US Army Corps of Engineers®

Chatfield Dam and LAke,CO

Inclinometer 545, Sta. 81+10, 17' DS

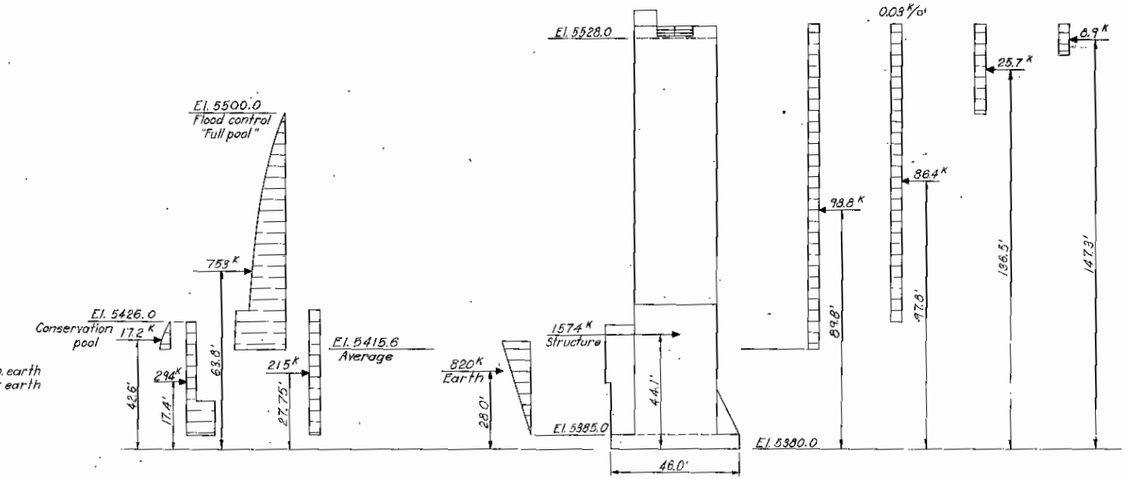
Checksum 2002 - Present

Reallocation Study **Plate D-31**



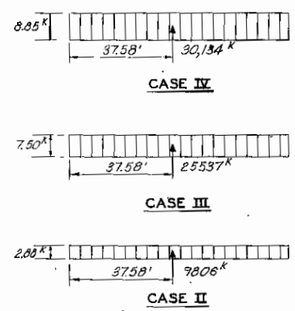
HORIZONTAL WATER PRESSURES

HORIZONTAL EARTH PRESSURES

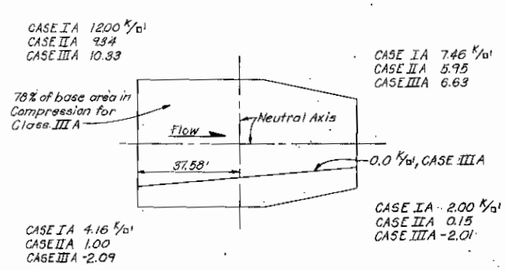


EARTHQUAKE FORCES

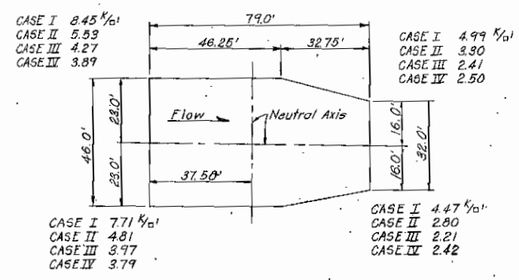
WIND PRESSURES



UPLIFT PRESSURES



FOUNDATION PRESSURES DUE TO EARTHQUAKE



FOUNDATION PRESSURES DUE TO WIND

LOADING CONDITIONS:

CASE I CONSTRUCTION CONDITION
- a. Reservoir empty
- b. Dead load of structure, incl. bridge & equip.
- c. Earth loads
- d. Wind load on side above backfill

CASE II NORMAL OPERATING CONDITIONS
- a. Reservoir at El. 5426, Conservation Pool
- b. All gates open
- c. Dead load of structure
- d. Earth loads
- e. Wind load on side above water surface
- f. Full uplift on base

CASE III FULL FLOOD CONDITION
- a. Reservoir at El. 5500, Full Pool
- b. Emergency gates closed
- c. Dead load of structure
- d. Earth loads
- e. Wind load above water surface
- f. Full uplift on base

CASE IV MAXIMUM FLOOD CONDITION
- Same as Case III except pool at El. 5521.6

Case IA, IIA, OR IIIA
- Same as Case I, II, or III, except earthquake is substituted for wind.

SHEAR-FRICTION FORMULA:

Sliding safety factor = $\frac{fV + sA}{H}$

CASE I	7.56	CASE IA	6.36
CASE II	13.64	CASE IIA	7.73
CASE III	13.06	CASE IIIA	6.33
CASE IV	13.00		

Allowable bearing pressure = 12.0 k.s.f.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPRD
	REVISIONS		

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: R. W. A.
DRAWN BY: E. J. G.
TRACED BY:
CHECKED BY: O. F. S.
SUBMITTED BY: Chas. E. Drake, CHIEF STRUCT. SECTION
APPROVED: CHIEF CIVIL DES. BRANCH
APPROVED: Charles L. Shipp, CHIEF ENGINEERING DIVISION
APPROVED: COL. U. S. E. DISTRICT ENGINEER

SOUTH PLATTE RIVER, COLORADO
CHATFIELD DAM AND RESERVOIR
OUTLET WORKS
INTAKE TOWER STABILITY ANALYSES

DATE: JUNE 1967
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

CHATFIELD DAM AND LAKE
SOUTH PLATTE RIVER BASIN
LITTLETON, COLORADO

DAM SAFETY EVALUATION REPORT

PROJECT MANAGEMENT PLAN

1. PRODUCT DEFINITION

It has been proposed to raise the normal reservoir elevation of the Chatfield Reservoir by up to 12 feet, from El. 5432 Ft. MSL to El. 5444 Ft. MSL, for the purpose of water supply. The water re-allocation study will actually evaluate three options, (1) no raise, (2) a five foot raise, and (3) a twelve foot raise. The final adopted plan will not increase the maximum surcharge reservoir elevation. The historic maximum reservoir elevation at Chatfield Dam is 5447.58. Ft. MSL. The purpose of this report is to evaluate potential dam safety concerns based on a permanent increase in the reservoir elevation. The evaluation is based strictly on static loading; however, historic information on previous seismic evaluations will be discussed. It is vital to address various aspects of design and performance to assure that the proposed modifications do not impact the continued safe operation of the dam and do not pose dam safety concerns.

2. PRODUCT DEVELOPMENT TEAM

The product development team consists of:

Michael T. Kelly, CENWO-ED-GB (Geotechnical Engineer)

Larkin Whistler, CENWO-ED-DF (Structural Engineer)

Eric Laux, CENWO-PM-C (Project Manager)

3. QUALITY CONTROL PROCESS

The quality control process will consist of a peer review for each discipline invoved in the product, a quality control review and an independent technical review. All comments will be resolved to the satisfaction of the Peer Review Team, Quality Control Review Team and the Independent Technical Review Team. Those participating on these teams are the following:

PERR REVIEW TEAM

Bob Worden, CENWO-ED-GB (Geotechnical Engineer)

Lyle Peterson, CENWO-ED-DF (Structural Engineer)

QUALITY CONTROL REVIEW TEAM

Richard Taylor, Chief , CENWO-ED-GB

Bruce Harris, Chief, CENWO-ED-GB

INDEPENDENT TECHNICAL REVIEW TEAM

Joseph Topi, CENWK-EC-GD (Geotechnical Engineer)

4.0 SCHEDULE

The proposed schedule milestone dates for the quality control reviews are given below.

Daft Report Complete by 15 Nov 08

Independent Technical Reviews Complete by 1 Dec 08

Peer Reviews Complete by 1 Jan 09

Quality Control Review Complete by 15 Jan 09

Final Report Complete by 1 Feb 09

5.0 DOCUMENTATION

Documentation of the quality control process will be recorded on the following forms. Reviewers will sign and date the forms after their review is complete.

CHATFIELD DAM AND LAKE
SOUTH PLATTE RIVER BASIN
LITTLETON, COLORADO

DAM SAFETY EVALUATION REPORT
PEER REVIEW CERTIFICATION

The undersigned certify that the Chatfield Dam Safety Evaluation report has been reviewed and that all significant comments generated have been addressed.

DATE

APPROVED BY: _____
BOB WORDEN, P.E. SOILS SECTION B,
GEOTECHNICAL ENGINEERING AND SCIENCES BRANCH,
ENGINEERING DIVISION

APPROVED BY: _____
LYLE PETERSON, P.E. STRUCTURAL/ INTERIOR DESIGN
SECTION, ENGINEERING DIVISION

CHATFIELD DAM AND LAKE
SOUTH PLATTE RIVER BASIN
LITTLETON, COLORADO

DAM SAFETY EVALUATION REPORT
QUALITY CONTROL REVIEW CERTIFICATION

The undersigned certify that Chatfield Dam Safety Evaluation Report has been reviewed and that all significant comments generated by the quality control review team have been addressed.

DATE

APPROVED BY: _____
RICHARD TAYLOR, P.E.. CHIEF, SOILS SECTION B
GEOTECHNICAL ENGINEERING AND SCIENCES BRANCH,
ENGINEERING DIVISION

APPROVED BY: _____
BRUCE HARRIS, P.E. CHIEF, STRUCTURAL/INTERIORS SECT.,
DESIGN BRANCH, ENGINEERING DIVISION

CHATFIELD DAM AND LAKE
SOUTH PLATTE RIVER BASIN
LITTLETON, COLORADO

DAM SAFETY EVALUATION REPORT

INDEPENDANT TECHNICAL REVIEW CERTIFICATION

The undersigned certify that the Chatfield Dam Safety Evaluation Report has been reviewed.

DATE

APPROVED BY: _____
Joseph Topi, CENWK-EC-GC

POST-LIQUEFACTION STABILITY ANALYSES DECEMBER 2010

CHATFIELD DAM & LAKE SOUTH PLATTE RIVER BASIN LITTLETON, COLORADO

U.S. Army Corps
Of Engineers
Omaha District
Final Report

Post-Liquefaction Stability Analyses
Chatfield Dam
Littleton, Colorado

Table of Contents

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5.0 Adopted Design Parameters	3
5.1 Embankment Geometry	3
5.2 Embankment Zoning	3
5.3 Foundation	5
5.4 Shear Strengths	5
5.5 Phreatic Surfaces	6
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6.1 Steady State Cases	7
6.2 Post Liquefaction Cases	8
7.0 Conclusions	9
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Appendix A – Excerpts From Embankment Criteria and Performance Report

Appendix B – Determination of Residual Shear Strength

Appendix C – Steady-State Seepage Stability Analyses

Appendix D – Post-Liquefaction Stability Analyses

Post-Liquefaction Stability Analyses
Chatfield Dam
Littleton, Colorado

1.0 Introduction This report presents the results of stability analyses performed on zones of the Chatfield Dam foundation that have been identified as susceptible to liquefaction (CENWO, 2009a).

2.0 Background A liquefaction assessment was performed in April 2009 as part of the water supply reallocation study for Chatfield Dam. The reallocation study is evaluating three options for a reservoir raise including: 1) no raise, 2) a five-feet raise in the multi-purpose pool, and 3) a 12-feet raise in the multi-purpose pool.

The scope of the liquefaction assessment (CENWO, 2009a) included an evaluation of the liquefaction potential of the Chatfield Dam embankment and foundation for both the existing multi-purpose reservoir (El. 5432) and the proposed 12-feet raise (El 5444). Granular soils were evaluated using the "Simplified Seed Method" (Youd et.al., 2001) which defines a Factor of Safety (F.S.) as the Cyclic Resistance Ratio (CRR) divided by the Cyclic Stress Ratio (CSR). The CRR is based on Standard Penetration Test (SPT) blow counts, corrected for fines content and hammer efficiency and normalized to an effective overburden pressure of one ton per square foot $(N_1)_{60}$. For the purpose of the liquefaction assessment, Factors of Safety less than 1.1 were deemed to liquefy.

The liquefaction assessment concluded that:

- The Chatfield Dam embankment would most likely be safe against liquefaction for a 6.0 (Mw) maximum credible earthquake with a PGA of 0.32g.
  Evaluation of the Chatfield Dam foundation indicates zones of liquefaction are likely along the upstream and downstream slope in the valley section.

- Review of soil conditions along the right abutment tends to indicate saturated zones of relatively loose silty sand and sand that may be prone to liquefaction.

- Recommendations included conducting post-earthquake limit equilibrium slope stability analyses to evaluate the stability of the upstream and downstream slopes in the valley section and right abutment section due to the potential for liquefaction of the foundation soils.

3.0 Cases Considered Two cross-sections were selected for post-liquefaction slope stability analyses: a maximum valley section at Station 95+00 and a right abutment section at Station 57+60. For each combination of section and slope, two multi-purpose pool levels were considered: the existing pool level (EL. 5432) and a 12-feet raise (El. 5444).

The maximum valley section was evaluated in the previously discussed liquefaction assessment. Based on the F.S. results at Station 95+00 and adjacent borings, an upstream liquefied zone was identified from El. 5375 to El. 5380 and a downstream liquefied zone was identified from El. 5352 to El. 5361.

The right abutment section was evaluated in the 1986 Seismic Evaluation (CENWO, 1986). The SPT values for this section were taken in holes advanced with a churn drill, so there is some concern that the SPT results were influenced by the drilling operation. However, the values were used only for relative comparisons with adjacent values and to identify low SPT zones. Based on the SPT results at Station 57+60 and adjacent borings, an upstream liquefied zone was identified from El. 5426 to El. 5432 and a downstream liquefied zone was identified from El. 5411 to El. 5432. The residual shear strength was determined from the blow counts of nearby SPT-12, which was evaluated in the liquefaction assessment (CENWO, 2009a).

For each section and pool level, two conditions for the horizontal extent of the potential liquefied zone were assumed: a) a zone extending beneath the entire upstream or downstream slope, and b) a zone extending ±100 feet of the embankment toes. Sketches of these liquefied zones are shown on Figures 1a and 1b. The zone under the entire slope is considered conservative, while the zone under the embankment toes is considered more realistic, given that the overburden confining pressure increases with increasing embankment fill height, which reduces liquefaction potential under the slope.

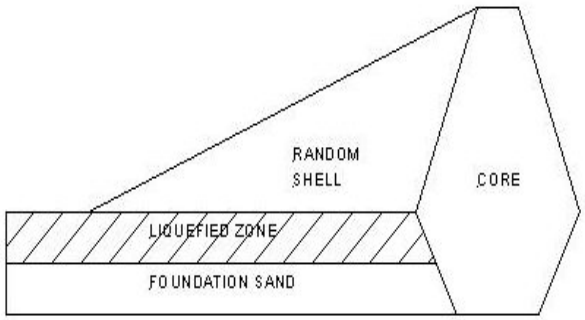

Figure 1a: Liquefied Zone Under Embankment Slope

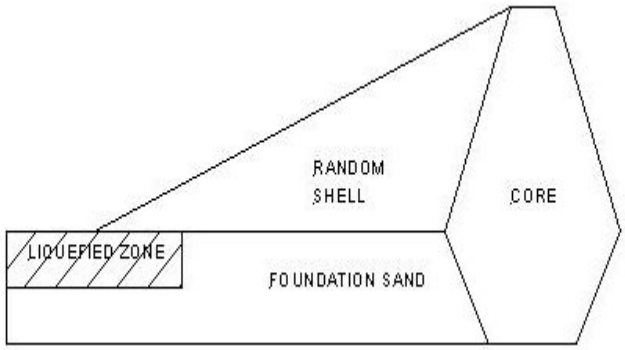

Figure 1b: Liquefied Zone Under Embankment Toe

Prior to performing the post-liquefaction stability analyses, the original design static stability analyses for the steady state seepage condition were reanalyzed using Spencer's method. The embankment geometry, foundation conditions, pool levels, and peak effective shear strengths (CD or S) were obtained from the Embankment Criteria and Performance Report (CENWO, 1980). Excerpts from this report are presented in Appendix A.

4.0 Analytical Approach The analytical approach was based on the guidance provided in the draft EM 1110-2-6001, "Seismic Stability of Earth and Rock Fill Dams," Chapter 8, "Post-Earthquake Stability Analysis" (USACE, 1998). This approach uses the effective stress parameters for the non-liquefied materials and an undrained residual strength for the liquefied zones. Stability analyses are conducted using circular arcs or non-circular surfaces and Spencer's method.

5.0 Adopted Design Parameters

5.1 Embankment Geometry The embankment geometry for the valley section (Sta. 95+00) was obtained from the "Embankment Criteria and Performance Report" (CENWO, 1980). The embankment geometry for the right abutment section (Sta. 57+60) was obtained from the 1986 Seismic Evaluation (CENWO, 1986).

5.2 Embankment Zoning The Chatfield Dam is a rolled, zoned, earthfill embankment. The embankment zoning consist of a symmetrical central impervious core extending to the Dawson formation bedrock, upstream and downstream random material shells, and a downstream pervious inclined sand drain with continuous outlets adjacent to the impervious core. The outer portion of the downstream random zone includes a zone specifically for all Dawson formation materials excavated from the spillway and outlet works excavations. This was done to keep the Dawson formation material least susceptable to saturation. A cross-section of the maximum valley section (station 95+00) is presented in Figure 2.

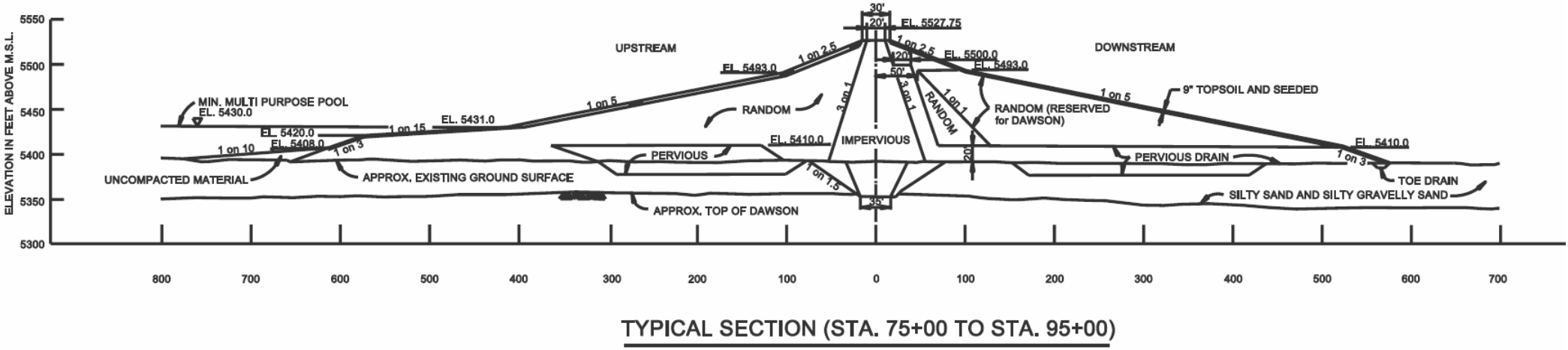

Figure 2: Embankment Zoning and Foundation Conditions in Valley

5.3 Foundation The dam foundation consists of sands, gravels, and sandy clay alluvium derived from the weathering and erosion of the parent materials of the mountains to the west, underlain by uncemented sand and sandy gravel and the Dawson formation bedrock. This study focuses on the granular alluvium and overburden soils overlying the Dawson. A cross-section of the maximum valley section is presented in Figure 2.

5.4 Shear Strengths The peak effective stress parameters (CD or S strengths) were selected from the "Embankment Criteria and Performance Report" (CENWO, 1980) for the non-liquefied materials (See Appendix A). These values are presented in Table 1.

Table 1: Adopted Peak Effective Stress (CD or S) Shear Strengths

Material	Cohesion (psf)	Friction angle (degrees)
Embankment		
Impervious	0	24.3
Random	0	24.3
Pervious	0	36.1
Dawson Fm.	0	22.3
Foundation		
Clay	0	20.8
Sand	0	33.0
Dawson Fm.	0	15.0

For the liquefied zones, an undrained residual strength was determined from a plot developed by Seed et.al., as reproduced in a report by Marcuson, Hynes and Franklin (1990). This plot (Figure 3) relates the undrained residual strength (in pounds per square foot) to the corrected, equivalent clean sand, SPT blow counts $(N_1)_{60}$.

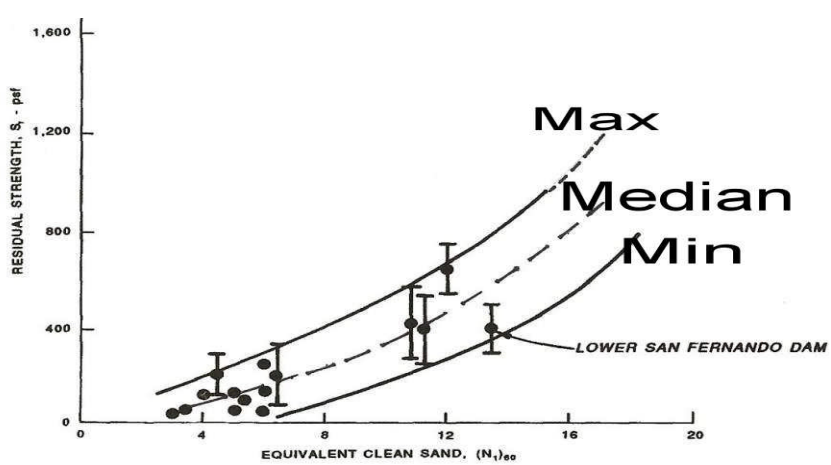

Figure 3: Relationship Between Residual Strength and SPT N-values (Marcuson, Hynes and Franklin, after Seed et.al.)

Corrected SPT values corresponding to Factors of Safety ≤ 1.1 were used to determine the residual shear strength for the liquefied zones. Three residual strength levels were considered:

1. Residual Strength Level 1 (RSL-1). Residual strengths for corrected SPT values were determined from the "Median " line of Figure 3. Individual residual shear strength values were ranked and an adopted design value was selected such that two-thirds (67 percent) of the test values exceed the adopted design value (USACE, 1970).

2. Residual Strength Level 2 (RSL-2). Residual strengths for corrected SPT values were determined from the "Median " line of Figure 3. Individual residual shear strength values were ranked and an adopted design value was selected such that one half (50 percent) of the test values exceed the adopted design value.

3. Residual Strength Level 3 (RSL-3). Residual strengths for corrected SPT values were determined from the "Max" line of Figure 3. Individual residual shear strength values were ranked and an adopted design value was selected such that one half (50 percent) of the test values exceed the adopted design value.

The corrected SPT values, selected residual strengths, and calculation for the adopted design residual strength for each strength level are presented in Appendix B. The adopted residual shear strengths are summarized in Table 2.

Table 2: Adopted Undrained Residual Shear Strengths

Location	**Residual Strength, psf**		
	RSL-1	**RSL-2**	**RSL-3**
Station 95+00			
Upstream	470	480	680
Downstream	540	560	790
Station 57+60			
Upstream	760	880	1120
Downstream	760	880	1120

5.5 Phreatic Surfaces The phreatic surfaces for the maximum valley section (Station 95+00) were obtained from the Liquefaction Assessment (CENWO, 2009). The phreatic surface for the right abutment section (Station 57+60) was obtained from the Seismic Evaluation (CENWO, 1986).

6.0 Results Non-circular, block failure surfaces were analyzed for each upstream or downstream stability case with Spencer's method, utilizing the 2007 version of SLOPE/W, developed by Geo-Slope International, Ltd.

For the re-analysis of the steady state seepage cases, the critical slide plane and peak effective strengths were used, as presented in the Embankment Criteria and Performance Report (CENWO, 1980). Excerpts from this report are presented in Appendix A. The intent of these re-analyses was to compare the current methodology (Spencer's method) with the method used for the original design.

For each post-liquefaction stability case, the sliding elevation was assumed horizontal and the location of the active and passive wedges were iterated until the coordinates corresponding to the critical F.S. were bounded by higher F.S. values. A minimum value of 1.30 was adopted for the post liquefaction factor of safety (CENWO, 2009a).

6.1 Steady State Seepage Cases Two embankment sections were considered in the original design, i.e., Station 95+00 and Station 68+50. Station 95+00 is typical of the valley section from Station 75+00 to Station 95+00. The embankment attains a height of about 117 feet and the foundation sand and clay are about 55 feet thick. Station 68+50 is typical of the right valley section. The embankment is about 131 feet high, with the Dawson Formation at the ground surface under the downstream slope and 30 to 40 feet below the ground surface under the upstream slope.

The results of the re-analysis of the steady seepage cases at Station 95+00 and Station 68+50 are presented on Table 3. These results indicate the factors of safety determined with Spencer's method exceed those factors of safety determined during the original design. Figures C-1 and C-2 in Appendix C present a comparison of the original stability analysis geometry and loading with the graphical output from the Slope/W re-analysis of each case.

Table 3: Steady State Seepage Factors of Safety

Station	Factor of Safety		
	Original	Re-Analysis	
		Janbu's Method	Spencer's Method
95+00	1.43	1.46	1.74
68+50	1.62	1.57	1.84

The difference in the Factor of Safety between the original analyses and the re-analyses using Spencer's method is due to the side force assumptions and statics of each method. The USACE method used in the original design analyses assumes a side force orientation and solves only for horizontal force equilibrium. Spencer's method iteratively determines the side force orientation and is statically determinate. Janbu's Generalized method, which makes assumptions similar to the USACE method, was used to analyze the same Slope/W model. The results, shown in Table 3, substantiate the original design analyses and confirm the difference in factor of safety is due to the analytical method.

6.2 Post-Liquefaction Cases

6.2.1 Station 95+00 The stability analysis results for the maximum valley section are summarized on Table 4. The upstream embankment factors of safety range from 1.18 to 2.38, depending on conditions and assumptions utilized. The downstream embankment factors of safety range from 1.17 to 1.85, depending on conditions and assumptions utilized.

Table 4: Post Earthquake Factors of Safety, Station 95+00

Liquefied Zone Extent	Residual Strength		
	RSL-1	RSL-2	RSL-3
Pool El. 5432			
Upstream Slope	1.18	1.19	1.40
" Toe	1.72	1.74	2.15
Downstream Slope	1.18	1.19	1.33
" Toe	1.68	1.70	1.85
Pool El 5444			
Upstream Slope	1.24	1.25	1.44
" Toe	1.92	1.95	2.38
Downstream Slope	1.17	1.18	1.32
" Toe	1.66	1.67	1.83*

* Further details of this case are presented in Appendix D.

The case representing pool El. 5444, with a liquefied zone limited to the downstream toe and the RSL-3 residual shear strength (F.S. = 1.83) is considered representative of the post-earthquake stability at this station since the overburden confining stress is lowest at the embankment toe. This case is presented on Figure D-1 in Appendix D.

6.3.1 Station 57+60 The stability analysis results for the right abutment section are summarized on Table 5. The upstream embankment factors of safety range from 1.15 to 2.75, depending on conditions and assumptions utilized. The downstream embankment factors of safety range from 1.58 to 3.75, depending on conditions and assumptions utilized.

Table 5: Post Earthquake Factors of Safety, Station 57+60

Liquefied Zone Extent	Residual Strength		
	RSL-1	RSL-2	RSL-3
Pool El. 5432			
Upstream Slope	1.16	1.26	1.44
" Toe	2.18	2.18	2.75
Downstream Slope	1.58	1.67	1.84
" Toe	3.68	3.70	3.75

Pool El 5444			
Upstream Slope	1.15	1.24	1.42
" Toe	2.10	2.29	2.68*
Downstream Slope	1.58	1.67	1.84
" Toe	3.62	3.64	3.69

* Further details of this case are presented in Appendix D.

The case representing pool El. 5444, with a liquefied zone limited to the upstream toe and the RSL-3 residual shear strength (F.S. = 2.68) is considered representative of the post earthquake stability at this station since the overburden confining stress is lowest at the embankment toe. This case is presented on Figure D-2 in Appendix D.

7.0 Conclusions

The results of this study suggest the following conclusions:

- Cases representing the liquefied zone at the toes of the upstream and downstream slopes are considered the most representative of the field conditions.

- The conservative cases combining the lowest residual strength (RSL-1) and a liquefied zone extending under the entire slope length have a F.S. of nominally 1.2.

- All F.S. determined using the RSL-3 residual strength exceed the minimum F.S. of 1.3, regardless of the horizontal extent of the liquefied zone.

- The combination of the toe liquefied zones and the RSL-3 residual strength best represent the liquefaction potential of the Chatfield Dam foundation. The minimum Factor of Safety for these cases is 1.83 for the Station 95+00 section and 2.68 for the Station 57+60 section.

- None of the critical failure surfaces breach the embankment crest.

8.0 References

CENWO (1980). Embankment Criteria and Performance Report, Chatfield Lake, Colorado, South Platte River Basin. U.S. Army Corps of Engineers, Omaha District, April 1980.

CENWO (1986). Design Memorandum No. PC-44, South Platte River Basin, Chatfield Lake, Colorado, Seismic Evaluation. U.S. Army Corps of Engineers, Omaha District, November 1986.

CENWO (2009a). Liquefaction Assessment, Chatfield Dam & Lake, South Platte River Basin, Littleton, Colorado. U.S. Army Corps of Engineers, Omaha District, April 2009.

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Marcuson III, W. F, Hynes, M. E. and Franklin A. G. (1990). "Evaluation and Use of Residual Strength in Seismic Safety Analysis of Embankments", Earthquake Spectra, Volume 6, No.3, pp. 529-572.

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Youd, T.L., et.al, (2001). "Liquefaction Resistance of Soils: Summary Report From the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Volume 127, No. 10, pp 817-833.

APPENDIX A

EXCERPTS FROM EMBANKMENT CRITERIA AND PERFORMANCE REPORT

SOUTH PLATTE RIVER BASIN

CHATFIELD LAKE, COLORADO

EMBANKMENT CRITERIA AND PERFORMANCE REPORT

United States Army
Corps of Engineers
...Serving the Army
...Serving the Nation

Omaha District

APRIL 1980

3.11.2.6. Seepage Under or Around Cutoff. Investigations were made to determine whether seepage could be a problem either under or around the cutoff trench. It was found that any seepage that might occur under the cutoff in the sandstones of around the end of the cutoff in the right abutment would be of such a small quantity that it would not be particularly noticeable. Piezometers were installed in the sandstones of the Dawson Formation near the downstream toe of the embankment to monitor seepage pressures that occur in the sandstones.

3.11.2.7. Underground Water Rights. In studies concerning the positive cutoff trench extending to bedrock, it was assumed that the groundwater table immediately downstream of the dam would be adversely affected and may produce serious problems for downstream holders of underground water rights. In connection with this, the Colorado Water Conservation Board was asked to assist in determining the criteria that should be considered for underground water requirements in the area. They concluded that with one or two possible exceptions, an impervious cutoff would have no noticeable effect on the majority of wells in existence and that even if some effect could be demonstrated on the remainder of the wells, the well owners could not prove a legal injury since they were illegally diverting water from the South Platte River. Their conclusion was based on a study area of five miles downstream from the dam, which included 35 wells on record, 18 of which were able to be actually located in the field. Their study indicated that most of the wells were located a distance of a mile or more from the dam site and were supplied largely from irrigation ditches.

3.12. Design Shear Testing.

3.12.1. Remolded Testing. Shear tests were conducted on remolded samples of materials which were representative of materials to be encountered in the required excavations and borrow areas. The

remolded samples were tested at 95 percent of maximum density, as determined by AASHO T-99-57A, at optimum and optimum plus 3 percent moisture content. A single test usually consisted of three specimens tested at different confining stresses. A total of 16 unconsolidated undrained "Q" tests; 20 consolidated-undrained "R" tests; and 18 consolidated-drained "S" tests were performed. Samples for "R" tests were saturated by back pressure before shearing. Triaxial specimens were 1.4 inch diameter except for a few at 3.9 inch diameter for coarse grained material. Direct shear tests were 3 in. by 3 in. by 0.5 in. and were sheared about 9.5 inch at a rate of about 0.0038 inch per minute. Test summaries showing adopted strengths are shown on Plates B-55 thru B-57.

3.12.2. Undisturbed Testing. Triaxial ("Q" and "R") and direct shear ("S") tests were performed on selected undisturbed samples of the clays in the valley foundation, and abutments plus the Dawson formation of bedrock. A single test usually consisted of 3 specimens tested at different confining stresses. Size of specimens were similar to that performed for remolded testing. Summaries of the foundation soils testing are shown on Plates B-58 thru B-60, and summaries of the shear tests on the Dawson Formation are on Plates B-61 thru B-69.

The total number of undisturbed tests conducted are as follows:

No. of Undisturbed Tests

Type of Test	No. of Shear Tests Foundation Soil	Foundation Bedrock
Q	18	11
R	15	4
S	14	19

3.12.3. Residual Testing. A total of 28 direct shear residual tests were performed on undisturbed Denison samples and on specimens obtained from cubic foot box samples of the Dawson Formation materials. Discussion and results are given in paragraph 3.12.4.3. The test summaries are shown on Plates B-70 and B-71.

3.12.4. Test Results.

3.12.4.1. Embankment Materials. Most of the remolded testing was concentrated on the weaker materials from each area of excavation. The impervious and random materials were chosen to have identical strengths and the final adopted strength was based primarily on the lowest strength of all the material types tested. Additionally, since the majority of the material would come from excavations where the moisture content was from 2 to 6 percent dry of optimum, the final adopted shear strengths were based on optimum moisture content specimen testing.

It was determined that "Q" tests conducted at optimum moisture were about twice the strength of those conducted at optimum plus 3 percent.

3.12.4.2. Foundation Soils. The majority of tests performed on foundation materials were on the weaker surface clays in the valley. Results indicated material of relatively low shear strength which ultimately was required to be removed to satisfy embankment stability requirements.

Results of testing indicated considerable ranges in shear strength which gave evidence to the heterogeneous nature of the foundation soils in general. Adopted strengths were based on the lowest test strengths obtained.

3.12.4.3. Bedrock. Tests on the Dawson Formation materials was generally confined to the clay-shale material which was thought to be weaker than the silty or sandy shales, sandstones and siltstones. Specific concentration was made of the more weathered bedrock. Additionally, since the Dawson Formation contains numerous slickensides of all sizes and degrees, the testing and correlation concerned this effect upon the strength. Results of the tests indicated that the slickensides in the bedrock appeared to have little

effect on the strength while the affects of weathering appeared to give lower strengths.

Stress-strain curves on direct-shear tests of the Dawson Formation exhibited sharp peaks and substantial differences between peak strengths and strength at the end of the strain, commonly referred to as ultimate strength. Because of the relatively sharp drop in strength with strain and the slickensided nature of the Formation, it was thought that slight additional amounts of horizontal movement may lower the strength toward a residual strength which could be considerably lower than the ultimate strength. As a consequence, a residual testing program was developed. Tests were performed on precut samples both by MRD and SWD laboratories in direct shear boxes having a size of 3"x3"x1". Total displacements ranged from 5 to 11.6 inches with residual strength usually being reached at from 4.4 to 11 inches. The range in residual strengths ranged from $\phi = 5°$ to $\phi = 32°$.

The final adopted strength of the Dawson Formation "S" strength was a practical value selected as a reasonable and conservative strength for use in stability computations. The value $\phi = 15°$ is approximately midway between a peak value of $\phi = 24°$ and a residual value of $\phi = 8°$.

A range of direct shear strengths by type of material for the Dawson Formation is given below and is also shown on Plate B-69:

Type of Material	Range of Direct Shear Strength	
	Peak	Ultimate
Clay shale	19° to 27°	12° to 23°
Silty shale & Siltstone	27° to 38°	23° to 33°
Sandy shale & Sandstone	38° to 42°	33° to 37°

A summary of residual shear strength test data and mineral composition of the Dawson Formation are shown on Plate B-71.

3.12.5. Summary of Adopted Design Strengths. The adopted shear strengths of the embankment and foundation materials which have been used in stability analyses computations are as follows:

Material	Unconsolidated-Undrained "Q" Strength			Consolidated-Undrained "R" Strength			Consolidated Drained "S" Strength		
	tan Ø	Ø	coh-T/SF	tan Ø	Ø	coh-T/SF	tan Ø	Ø	coh-T/SF
Embankment									
Impervious	0.042	2.4°	1.5	0.17	9.7°	0.50	0.45	24.3°	0.0
Random	0.042	2.4°	1.5	0.17	9.7°	0.50	0.45	24.3°	0.0
Pervious	0.73	36.1°	0.0	0.73	36.1°	0.00	0.73	36.1°	0.0
Dawson Fm.	0.00	0.0°	2.0	0.20	11.3°	0.40	0.41	22.3°	0.0
Foundation									
Clay	0.00	0.0°	0.28	0.15	8.5°	0.30	0.38	20.8°	0.0
Sand	0.65	33.0°	0.00	0.65	33.0°	0.00	0.65	33.0°	0.0
Dawson Fm.	0.00	0.0°	2.70	0.35	19.3°	0.40	0.27*	15.0°*	0.0*

*Value used in lieu of "S" strength.

3.12.6. Additional Shear Testing of Dawson Fm. A post-design testing program was done for soft seam materials of the Dawson Formation. The results of the testing was reported in a Supplement to Design Memorandum No. PC-24, December 1970. The testing was a result of concerns voiced during a Board of Consultants meeting and the objective was to ascertain whether shear strengths of soft seam material might be lower than shear strengths previously obtained for the Dawson Formation. Testing was also done to investigate consolidation and mineralogical characteristics of the seam. Samples were obtained from box samples which were cut from test pits 8 and 9 located in the outlet works area. In addition, some specimens were cut directly into shear boxes. Photos 8 and 9, Plate A-8, show typical undisturbed sampling operations.

The testing program consisted of twelve (12) residual shear tests; and eleven (11) direct shear tests on the soft seam material. Only three of the tests were "precut" residuals similar to that done previously for the Dawson Formation.

Results of the tests indicated that both the residual and normal direct shear strengths of the soft seam materials were within the range of their respective strengths previously obtained for the Dawson Formation. Plate B-72 shows summary results of the testing.

Atterberg Limits and moisture content tests of the soft seam material was compared to the material above and below the seam and the following was found:

(1) The moisture content of the seam material was slightly higher than the surrounding shale.
(2) There was no appreciable difference between Atterberg Limits for the seam material and surrounding shale.
(3) Moisture contents of the seam material exceeded the plastic limit more consistently than the weathered shale or the shale above and below the seam.

Mineralogical tests on the shale and soft seam material indicated that percentages of various clay minerals in the seam material do not differ significantly from that found in the shale material above and below the seam. The dominant absorbed ion was the calcium ion which was also found to be dominant in previous tests on clay shale materials. The results of the mineralogical tests were highly supportive of the conclusion that the seam material is a gouge or fracture type of material and not a separately deposited material, such as bentonite.

3.13. Record Shear Tests. Twenty two undisturbed cubic-foot box samples were taken on the embankment materials by the Stage III Earthwork Contractor during the contract period. Plates C-1 thru C-6,

Appendix "C", show the locations of the box samples and the test results compared to design shear strengths.

The total number of record shear test series on the different materials are presented below:

No. of Record Shear Tests

Type of Test	Embankment Materials Imp & Random	Dawson Fm.
"Q"	12	3
"R"	9	2
"S"	9	2

3.14. Embankment Stability Analyses.

3.14.1. General. Stability analyses were performed for three embankment sections: (1) embankment section at station 95+00 where the embankment attains a maximum height of 137 feet and the depth of the alluvial material is about 55 feet. (2) The outlet works section, where the embankment attains a height of about 117 and alluvial material is 25 feet deep; and (3) the right valley embankment section at station 68+50 where the embankment is about 131 feet high but where the Dawson Formation is at the ground surface for the downstream portion of the section and 30 to 40 feet below the surface under the upstream portion of the section. Analyses consisted of four types of cases which simulate conditions of stress during the life of the structure. The cases are: (1) end of construction; (2) sudden drawdown; (3) partial pool and (4) steady seepage.

3.14.2. Method of Analysis. The sliding wedge method was used for the stability analyses. The factor of safety in the analyses is defined as the ratio of the available shear strength to the average necessary to maintain equilibrium. Most of the studies were performed with an RCA 301 computer using slope stability program 41-R3-1302C, "Slope Stability, Wedge Method."

Most of the analyses were performed in the conventional manner; however, some special cases were performed using at rest pressure conditions for driving forces when failure was assumed in the Dawson Formation. This was done as a means to account for strain incompatibility between the brittle Dawson Formation and the embankment materials. The earth pressure coefficient used for computing the driving forces was 0.5.

3.14.3. Seismic Coefficient. The stability analyses include an allowance for earthquake forces for all potential failure surfaces and cases studied except sudden drawdown from maximum pool. This was done by the addition of a horizontally directed static force in the computations with no change in strengths. The additional earthquake force is the product of a seismic coefficient and the weight of the sliding mass. The coefficient assumed for the analyses was 0.1.

3.14.4. Summary of Results. The following table summarizes the stability analyses results and Plates B-73 thru B-78 summarize each analyses.

CASE	ELEV. OF FAILURE PLANE	NORMAL FACTOR OF SAFETY	REQUIRED FACTOR OF SAFETY	EARTHQUAKE FACTOR OF SAFETY	REQUIRED EARTHQUAKE FACTOR OF SAFETY	SHEAR STRENGTH
END OF CONSTRUCTION						
Upstream-Sta 95+00	5410	2.62	1.3	1.82	1.0	"Q"
Downstream-Sta 95+00	5335	2.53	1.3	1.62	1.0	"Q"
PARTIAL POOL						
Sta 95+00	5410	1.49	1.5	1.04	1.0	"R"
Sta 104+35	5353	1.46	1.5	0.90	1.0	*
SUDDEN DRAWDOWN						
Max. Pool-Sta 95+00	5410	1.23	1.0	-	Not Req'd	"R"
Spillway Pool-Sta 95+00	5410	1.33	1.20	0.92	1.0	"R"
STEADY SEEPAGE						
Sta 95+00 (Conventional)	5300	1.43	1.5	0.86	1.0	*
Sta 95+00 (At-rest pressure)	5335	1.13	-	-	-	*
Sta 104+35(Conventional)	5320	1.58	1.5	0.92	1.0	*
Sta 68+50	5320	1.62	1.5	0.94	1.0	*

* The "S" strength was used for all materials except the Dawson Formation. A lower strength was adopted for the Dawson Formation in lieu of an "S" Strength.

APPENDIX B

DETERMINATION OF RESIDUAL SHEAR STRENGTH

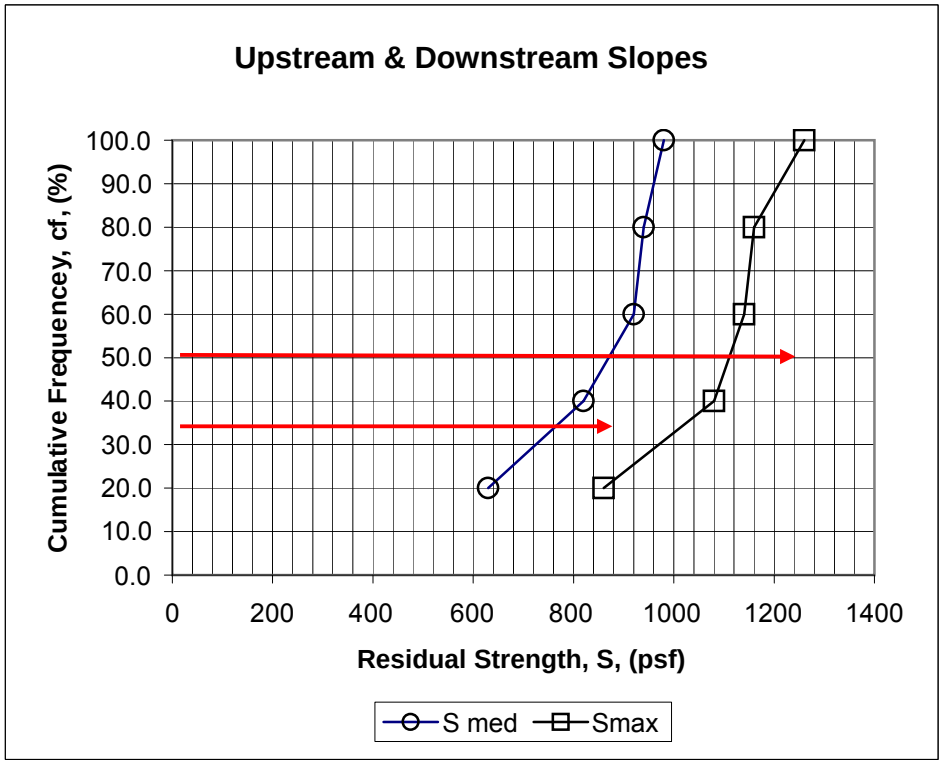
CHATFFIELD DAM
POST-LIQUEFACTION SHEAR STRENGTH

Station 57+60					
Upstream & Downstream					
$(N1)_{60}$ (bpf)	S_{med} (psf)	S_{max} (psf)	n (-)	$\sum n$ (-)	cf (%)
14.0	630	860	1	1	20.0
16.3	820	1080	1	2	40.0
16.5	920	1140	1	3	60.0
16.6	940	1160	1	4	80.0
17.6	980	1260	1	5	100.0

Notes:

1. $(N1)_{60}$ data from Boring SPT-12 for F.S. < 1.1
2. S values obtained from Seed et al. plot

Adopted Residual Shear Strength, (psf)			
Location	**RSL-1**	**RSL-2**	**RSL-3**
Upstream	760	880	1120
Downstream	760	880	1120

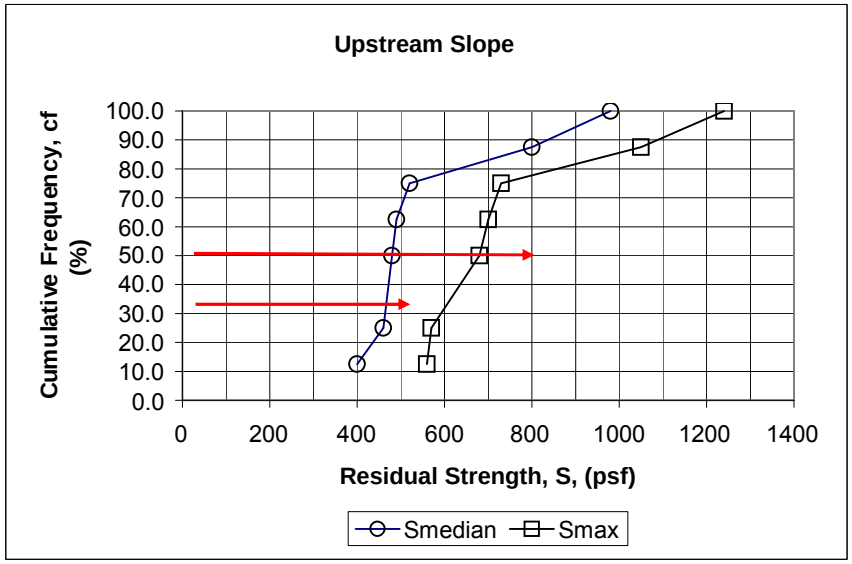


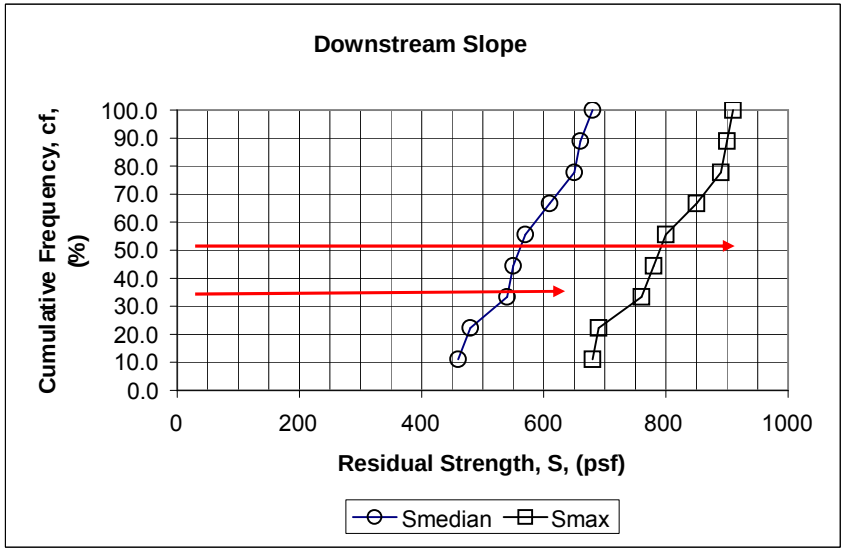
CHATFFIELD DAM
POST-LIQUEFACTION SHEAR STRENGTH

Station 95+00					
Upstream					
$(N1)_{60}$	S_{median}	S_{max}	n	∑n	cf
(bpf)	(psf)	(psf)	(-)	(-)	(%)
10.1	400	560	1	1	12.5
10.3	460	570	1	2	25.0
11.8	480	680	2	4	50.0
12.0	490	700	1	5	62.5
12.4	520	730	1	6	75.0
16.0	800	1050	1	7	87.5
17.6	980	1240	1	8	100.0
Downstream					
11.7	460	680	1	1	11.1
11.8	480	690	1	2	22.2
12.8	540	760	1	3	33.3
13.0	550	780	1	4	44.4
13.2	570	800	1	5	55.6
13.8	610	850	1	6	66.7
14.3	650	890	1	7	77.8
14.4	660	900	1	8	88.9
14.6	680	910	1	9	100.0

Notes:

1 Upstream $(N1)_{60}$ data from Borings SPT-10 & 14 for F.S. < 1.1
2 Downstream $(N1)_{60}$ data from Boring SPT 08-03 for F.S. < 1.1
3 S values obtained from Seed et.al. plot





Adopted Residual Shear Strength. (psf)			
Location	**RSL-1**	**RSL-2**	**RSL-3**
Upstream	470	480	680
Downstream	540	560	790

APPENDIX C

STEADY-STATE SEEPAGE STABILITY ANALYSES

CHATFIELD DAM
Steady-Seepage Stability Re-Analysis

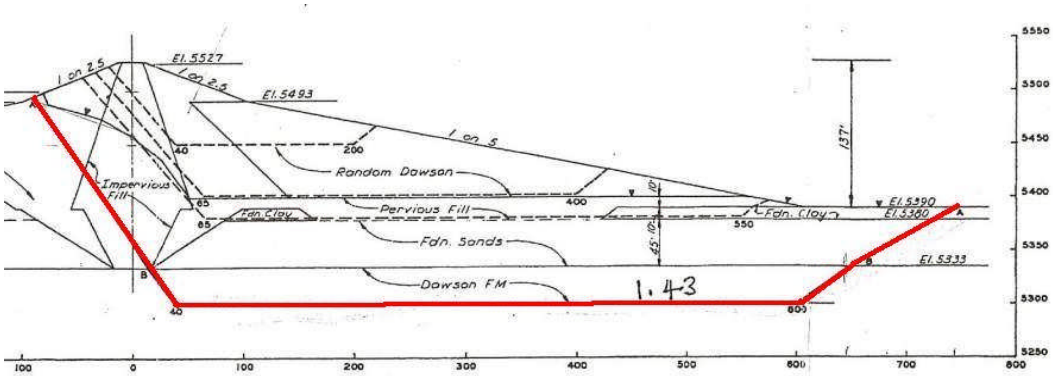


Figure C-1a: Original Stability Analysis from "Embankment Criteria and Performance Report," April, 1980.

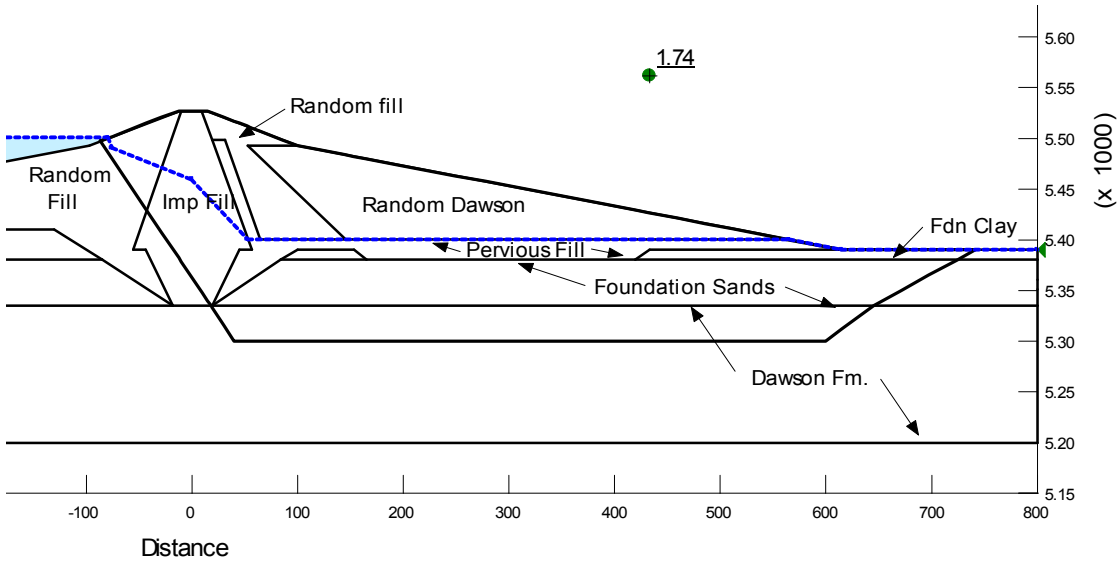


Figure C-1b: Re-Analysis Output from Slope/W

Figure C-1: Steady-Seepage Re-Analysis, Station 95+00

Station 95+00, Steady Seepage, Pool 5500

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File Information

Title: Chatfield Dam, Post Liquefaction Stability Assessment
Comments:
Created By: Stacey, Teryl L NWO
Revision Number: 45
Last Edited By: R.L.Donovan
Date: 09/04/2009
Time: 10:32:50 AM
File Name: Chatfield Sta 95 Steady Seepage.gsz
Directory: F:\Projects\Other\Chatfield Dam\
Last Solved Date: 09/04/2009
Last Solved Time: 10:32:56 AM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

Station 95+00 Pool 5500

Description: See Plate B-73 for referenced data.
Kind: SLOPE/W
Method: Spencer
Settings
- Apply Phreatic Correction: No
- PWP Conditions Source: Piezometric Line
- Use Staged Rapid Drawdown: No

SlipSurface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Fully-Specified

Critical slip surfaces saved: 1
Optimize Critical Slip Surface Location: No
FOS Distribution
FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

Embankment Impervious

Model: Bilinear
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi 1: 24.3 °
Phi 2: 17.2 °
Bilinear Normal: 3500 psf
Pore Water Pressure
Piezometric Line: 1

Embankment Dawson

Model: Bilinear
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi 1: 22.3 °
Phi 2: 17 °
Bilinear Normal: 3700 psf
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Embankment Random

Model: Bilinear
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi 1: 24.3 °
Phi 2: 17.2 °
Bilinear Normal: 3500 psf

Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Embankment Pervious

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 36.1 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Clay

Model: Bilinear
Unit Weight: 118 pcf
Cohesion: 0 psf
Phi 1: 20.8 °
Phi 2: 14.8 °
Bilinear Normal: 2500 psf
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Sand

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion: 0 psf
Phi: 33 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Dawson

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 15 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Limits

Left Coordinate: (-800, 5390) ft
Right Coordinate: (800, 5390.0789) ft

Fully Specified Slip Surfaces

Fully Specified Slip Surface 1

	X (ft)	Y (ft)
	-88	5499
	18	5335
	40	5300
	600	5300
	645	5335
	745	5392

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
	-800	5499.9853
	-79.5642	5500.1743
	-75.8814	5490.203
	0.3135	5460.2447
	52.5913	5400.1504
	565	5400
	615	5390
	800	5390.0789

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	1	1.70	(337.761, 5524.05)	378.06	(-86.8702, 5497.25)	(741.586, 5390.05)

Slices of Slip Surface: 1

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)

1	1	-83.21718	5491.6	534.96891	726.42301	86.444845	0
2	1	-77.7228	5483.099	754.36791	1540.7205	355.05183	0
3	1	-59.36778	5454.701	1810.2308	4522.2899	1224.5416	0
4	1	-35.72581	5418.123	3512.5875	8561.9653	1563.0435	496.88
5	1	-20.54873	5394.6415	4605.6485	11196.467	2040.1992	496.88
6	1	-11.25	5380.255	5274.9709	12769.451	2319.9291	496.88
7	1	-4.84325	5370.3425	5736.4305	13669.747	2455.7717	496.88
8	1	5.15675	5354.8705	6227.6683	15034.834	2726.2733	496.88
9	1	12.5	5343.5095	6410.1298	16005.783	2970.3508	496.88
10	1	16.5	5337.321	6509.3953	16484.376	3087.7725	496.88
11	1	18.53	5334.157	6561.2733	17123.372	2830.1058	0
12	1	24.53	5324.6115	6726.5708	18001.409	3021.0837	0
13	1	35	5307.9545	7015.0865	19452.47	3332.5868	0
14	1	42.5	5300	6973.2	27434	5482.4548	0
15	1	48.79565	5300	6521.6761	27171.894	5533.2092	0
16	1	54.29565	5300	6249.3033	26896.764	5532.4705	0
17	1	60.5	5300	6249.2222	26443.333	5410.9958	0
18	1	75.25	5300	6248.7805	25539.024	5168.8053	0
19	1	92.75	5300	6248.6207	24588.276	4914.0958	0
20	1	111.34435	5300	6248.4904	23892.091	4727.5884	0
21	1	133.78305	5300	6247.7804	23342.533	4580.5252	0
22	1	148.9387	5300	6247.5916	22971.567	4481.1757	0
23	1	158.75	5300	6247.4783	22792.174	4433.1378	0
24	1	178.66665	5300	6247.0596	22366.238	4319.1208	0
25	1	207	5300	6246.7066	21672.355	4133.2902	0
26	1	235.33335	5300	6246.0007	20978.473	3947.5541	0
27	1	263.66665	5300	6245.6478	20284.944	3761.818	0
28	1	292	5300	6244.9419	19591.061	3576.0819	0
29	1	320.33335	5300	6244.589	18897.532	3390.3458	0
30	1	348.66665	5300	6243.8831	18203.649	3204.6097	0
31	1	377	5300	6243.5301	17510.12	3018.8736	0
32	1	405.33335	5300	6242.8243	16816.237	2833.1375	0
33	1	426.25	5300	6242.5185	16242.963	2679.611	0
34	1	446.2	5300	6242.0455	15693.182	2532.4244	0
35	1	472.6	5300	6241.6667	15046.97	2359.3738	0
36	1	499	5300	6241.2879	14400.379	2186.2218	0

37	1	525.4	5300	6240.9091	13754.167	2013.1713	0
38	1	551.8	5300	6240.1515	13107.576	1840.1208	0
39	1	582.5	5300	6021.7143	12324.857	1688.922	0
40	1	607.5	5305.8335	5345.4943	13202.182	2105.193	0
41	1	630	5323.3335	4160.4121	10174.223	1611.3958	0
42	1	658.1579	5342.5	2965.1433	7669.3734	3054.9628	0
43	1	684.4737	5357.5	2029.837	5216.7982	2069.6368	0
44	1	710.7895	5372.5	1094.5636	2764.0579	1084.1823	0
45	1	732.76665	5385.027	313.44999	703.89445	148.31593	0

CHATFIELD DAM
Steady-Seepage Stability Re-Analysis

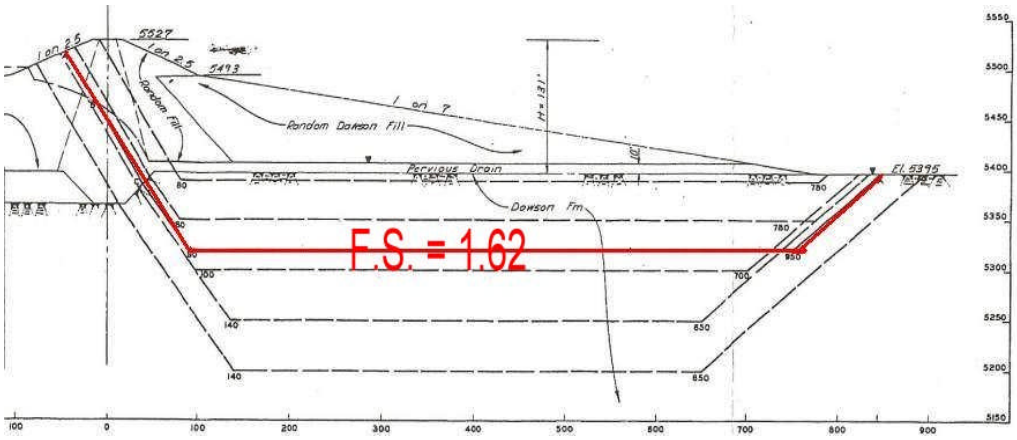

Figure C-2a: Original Stability Analysis from "Embankment Criteria and Performance Report," April, 1980.

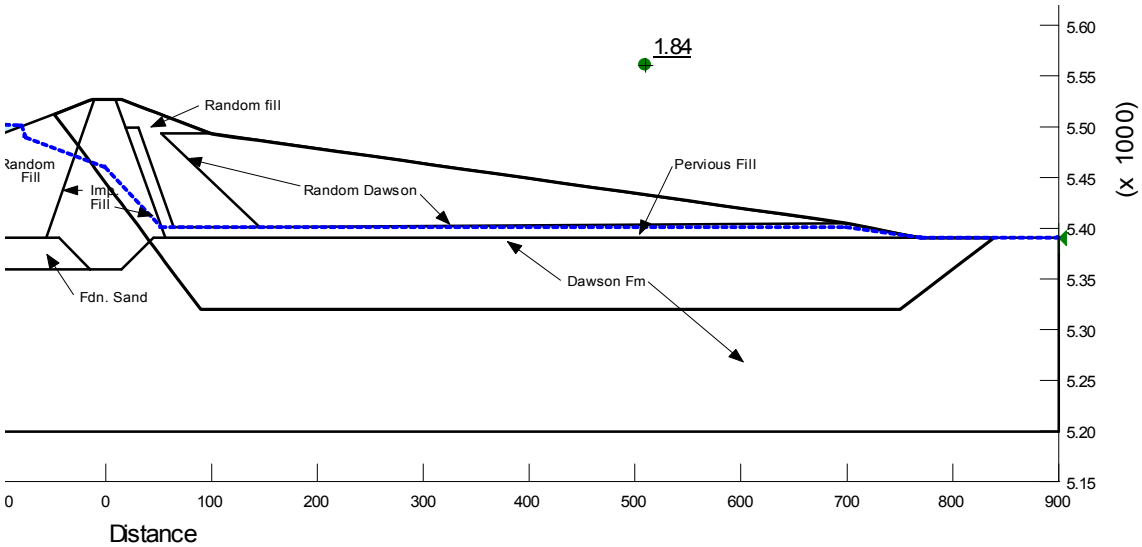

Figure C-2b: Re-Analysis Output from Slope/W

Figure C-2: Steady-Seepage Re-Analysis, Station 68+50

Station 68+50, Steady Seepage, Pool El. 5500

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File Information

Title: Chatfield Dam, Post Liquefaction Stability Assessment.
Comments:
Created By: R.L. Donovan
Revision Number: 50
Last Edited By: R. L. Donovan
Date: 09/08/2009
Time: 10:10:16 AM
File Name: Chatfield Sta 68+50 Steady Seepage.gsz
Directory: F:\Projects\Other\Chatfield Dam\
Last Solved Date: 09/08/2009
Last Solved Time: 10:10:22 AM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

Station 68+50 Pool 5500

Description: See Plate B-6 of Draft Water Supply Re-Allocation study.
Kind: SLOPE/W
Method: Spencer
Settings
- Apply Phreatic Correction: No
- PWP Conditions Source: Piezometric Line
- Use Staged Rapid Drawdown: No

SlipSurface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Fully-Specified

Critical slip surfaces saved: 1
Optimize Critical Slip Surface Location: No
FOS Distribution
FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

Embankment Impervious

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 24.3 °
Pore Water Pressure
Piezometric Line: 1

Embankment Dawson

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 22.3 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Embankment Random

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 24.3 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Embankment Pervious

Model: Mohr-Coulomb

Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 36.1 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Sand

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion: 0 psf
Phi: 33 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Dawson

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 15 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Limits

Left Coordinate: (-800, 5390) ft
Right Coordinate: (900, 5390.0789) ft

Fully Specified Slip Surfaces

Fully Specified Slip Surface 1

	X (ft)	Y (ft)
	-50	5514
	90	5320
	750	5320
	845	5395

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
	-800	5499.9853
	-79.5642	5500.1743
	-75.8814	5490.203
	0.3135	5460.2447
	52.5913	5400.1504
	700	5400
	770	5390
	900	5390.0789

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	1	1.84	(407.58, 5543.05)	396.191	(-48.88, 5512.45)	(838.72, 5390.04)

Slices of Slip Surface: 1

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	1	-37.280165	5496.374	-1332.1226	1666.7171	752.55163	0
2	1	-20.725875	5473.4345	-306.85143	4045.3081	1826.5266	0
3	1	-14.13571	5464.3025	101.30585	5013.0599	2217.742	0
4	1	-11.25	5460.3035	280.02287	5424.4337	2322.7906	0
5	1	-4.84325	5451.4255	676.84842	6220.9457	2503.2559	0
6	1	5.15675	5437.5685	1067.6088	7416.2321	2866.5133	0
7	1	12.5	5427.393	1175.8714	8257.5499	3197.5005	0
8	1	17.03	5421.116	1242.5819	8711.1899	3372.2058	0
9	1	24.53	5410.723	1353.1476	9437.8529	3650.3844	0
10	1	35.898205	5394.9695	1520.6556	10488.426	4049.1038	0
11	1	43.398205	5384.5765	1631.2195	12009.697	2780.9045	0

12	1	48.79565	5377.0975	1710.7767	12558.904	2906.7468	0
13	1	54.29565	5369.476	1913.9937	13123.106	3003.4726	0
14	1	60.5	5360.8785	2450.4315	13703.093	3015.1414	0
15	1	77.5	5337.3215	3920.2734	15449.36	3089.2095	0
16	1	95	5320	5000.8	22129	4589.4874	0
17	1	111.21795	5320	5000.4747	21683.581	4470.2248	0
18	1	133.6538	5320	5000.029	21280.655	4362.3805	0
19	1	151.9117	5320	4999.9254	20953.82	4274.8333	0
20	1	173.98085	5320	4999.6274	20559.753	4169.3232	0
21	1	204.0391	5320	4999.2947	20023.128	4025.6241	0
22	1	234.0973	5320	4998.6293	19486.504	3882.0142	0
23	1	264.15555	5320	4998.2966	18949.879	3738.3151	0
24	1	294.2138	5320	4997.964	18413.254	3594.6161	0
25	1	324.27205	5320	4997.2986	17876.629	3451.0061	0
26	1	354.3303	5320	4996.9659	17340.004	3307.3071	0
27	1	384.3885	5320	4996.6332	16803.379	3163.608	0
28	1	414.44675	5320	4996.3005	16266.754	3019.9089	0
29	1	444.505	5320	4995.6351	15730.129	2876.299	0
30	1	474.5632	5320	4995.3025	15193.504	2732.6	0
31	1	504.62145	5320	4994.9698	14656.879	2588.9009	0
32	1	534.6797	5320	4994.3044	14120.255	2445.291	0
33	1	564.73795	5320	4993.9717	13583.63	2301.5919	0
34	1	594.7962	5320	4993.639	13047.005	2157.8928	0
35	1	624.8544	5320	4992.9736	12510.38	2014.2829	0
36	1	654.91265	5320	4992.641	11973.755	1870.5839	0
37	1	684.9709	5320	4992.3083	11437.13	1726.8848	0
38	1	712.5	5320	4880.4	10816	1590.4392	0
39	1	737.5	5320	4657.6	10110.4	1461.0734	0
40	1	760	5327.8945	3964.4432	10272.939	1690.3564	0
41	1	787.17985	5349.3525	2536.9533	6496.1171	1060.8548	0
42	1	821.5396	5376.479	845.67393	2165.3419	353.60397	0

APPENDIX D

POST-LIQUEFACTION STABILITY ANALYSES

Table D-1: Adopted Shear Strengths

Material	Cohesion (psf)	Friction angle (degrees)
Embankment		
Impervious	0	24.3
Random	0	24.3
Pervious	0	36.1
Dawson Fm.	0	22.3
Foundation		
Clay	0	20.8
Sand	0	33.0
Dawson Fm.	0	15.0
Liquefied Zones		
Upstream	680	0
Downstream	790	0

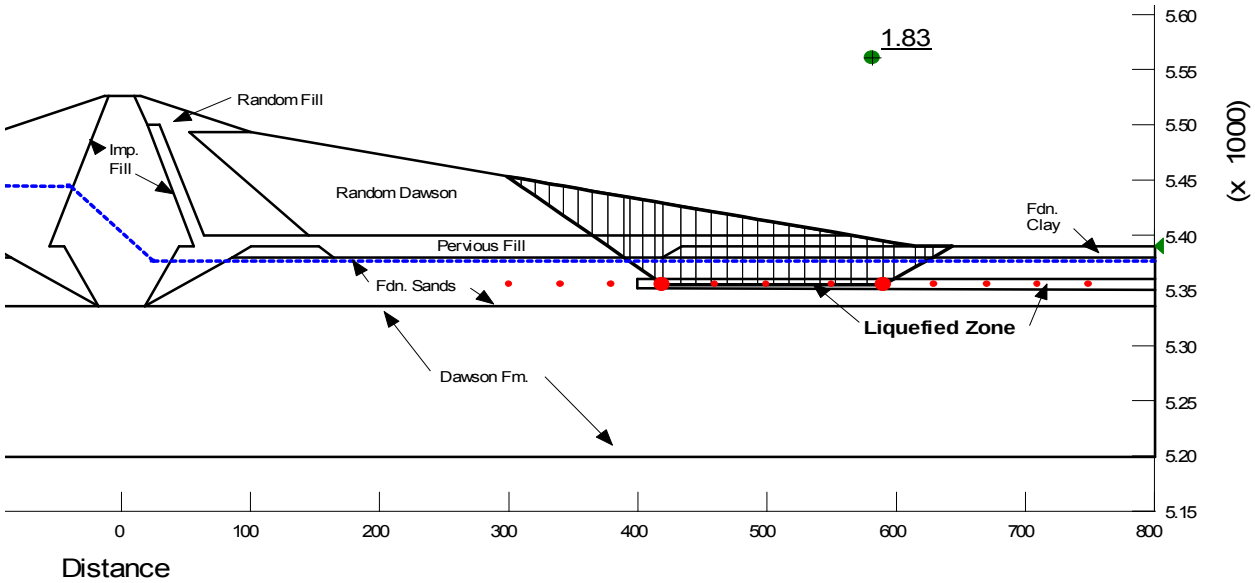

Figure D-1: Post-Liquefaction Slope Stability at Downstream Toe

Figure D-1: Sta 95+00, Pool El. 5444, Downstream Toe

Station 95+00 Pool El. 5444 Downstream Toe

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File Information

Title: Chatfield Dam, Post-Liquefaction Stability Assessment.
Comments:
Created By:
Revision Number: 49
Last Edited By: R.L. Donovan
Date: 09/01/2009
Time: 10:57:48 AM
File Name: Chatfield Sta 95 Pool 5444 - Min Liq - Max S - DS.gsz
Directory: F:\Projects\Other\Chatfield Dam\
Last Solved Date: 09/01/2009
Last Solved Time: 10:57:58 AM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

Station 95+00 Pool 5444

Description: See Plate B-73 for referenced data.
Kind: SLOPE/W
Method: Spencer
Settings
- Apply Phreatic Correction: No
- PWP Conditions Source: Piezometric Line
- Use Staged Rapid Drawdown: No

SlipSurface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Block

Critical slip surfaces saved: 1
Optimize Critical Slip Surface Location: No
FOS Distribution
FOS Calculation Option: Constant
Restrict Block Crossing: No
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 ft
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Materials

Embankment Impervious

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 24.3 °
Pore Water Pressure
Piezometric Line: 1

Embankment Dawson

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 22.3 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Embankment Random

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 24.3 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Embankment Pervious

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 36.1 °
Phi-B: 0 °
Pore Water Pressure
    Piezometric Line: 1

Foundation Clay

Model: Mohr-Coulomb
Unit Weight: 118 pcf
Cohesion: 0 psf
Phi: 20.8 °
Phi-B: 0 °
Pore Water Pressure
    Piezometric Line: 1

Foundation Sand

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion: 0 psf
Phi: 33 °
Phi-B: 0 °
Pore Water Pressure
    Piezometric Line: 1

Foundation Dawson

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 15 °
Phi-B: 0 °
Pore Water Pressure
    Piezometric Line: 1

Liquefied U.S. Foundation Sand

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion: 680 psf
Phi: 0 °
Phi-B: 0 °
Pore Water Pressure
    Piezometric Line: 1

Liquefied D.S. Foundation Sand

Model: Mohr-Coulomb

Unit Weight: 125 pcf
Cohesion: 790 psf
Phi: 0 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Limits

Left Coordinate: (-800, 5390) ft
Right Coordinate: (800, 5390.0789) ft

Slip Surface Block

Left Grid
Upper Left: (300, 5355) ft
Lower Left: (300, 5355) ft
Lower Right: (500, 5355) ft
X Increments: 5
Y Increments: 0
Starting Angle: 135 °
Ending Angle: 147 °
Angle Increments: 2
Right Grid
Upper Left: (550, 5355) ft
Lower Left: (550, 5355) ft
Lower Right: (750, 5355) ft
X Increments: 5
Y Increments: 0
Starting Angle: 33 °
Ending Angle: 45 °
Angle Increments: 3

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
	-800	5444
	-40	5444
	25	5376
	800	5376

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	245	1.83	(479.972, 5469.09)	159.547	(298.646, 5453.27)	(643.914, 5390.01)

Slices of Slip Surface: 245

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	245	304.1276	5448.8315	-4544.7103	320.35611	131.38762	0
2	245	315.0916	5439.953	-3990.7003	961.0825	394.16866	0
3	245	326.0556	5431.0745	-3436.6904	1601.7805	656.93808	0
4	245	337.0196	5422.196	-2882.6096	2242.5495	919.73656	0
5	245	347.9836	5413.3175	-2328.5996	2883.2475	1182.506	0
6	245	358.9476	5404.439	-1774.5897	3523.9455	1445.2754	0
7	245	370.6041	5395	-1185.5765	3873.4034	2824.5344	0
8	245	382.9531	5385	-561.59913	4604.7365	3357.8316	0
9	245	391.5974	5378	-124.80053	5223.8312	3392.3956	0
10	245	398.8723	5372.109	242.80206	5686.5415	3535.2057	0
11	245	408.4825	5364.327	728.41427	6327.8948	3636.3452	0
12	245	416.3938	5357.9205	1128.1772	7860.5251	0	790
13	245	426.25	5355.2025	1297.7868	8974.4833	0	790
14	245	439	5355	1310.4167	8680.8333	0	790
15	245	451	5355	1310.4167	8393.3333	0	790
16	245	463	5355	1310.4167	8105.1667	0	790
17	245	475	5355	1310.4167	7817.1667	0	790
18	245	487	5355	1310.4167	7529.1667	0	790
19	245	499	5355	1310.4167	7241.1667	0	790
20	245	511	5355	1310.4167	6953.1667	0	790
21	245	523	5355	1310.4167	6665.1667	0	790
22	245	535	5355	1310.4167	6377.1667	0	790
23	245	547	5355	1310.4167	6089.1667	0	790
24	245	559	5355	1310.4167	5801.1667	0	790
25	245	571.25	5355	1310.4	5494.64	0	790
26	245	583.75	5355	1310.4	5169.68	0	790

27	245	594.2483	5357.759	1138.2794	5243.8634	0	790
28	245	606.7483	5365.8765	631.7207	4610.5295	2583.8687	0
29	245	618.6686	5373.6175	148.66438	2990.2047	1845.3178	0
30	245	625.4169	5378	-124.79995	2207.9666	1433.8703	0
31	245	636.20545	5385.006	-561.97347	775.20898	294.47427	0

Table D-2: Adopted Shear Strengths

Material	Cohesion (psf)	Friction angle (degrees)
Embankment		
Impervious	0	24.3
Random	0	24.3
Pervious	0	36.1
Dawson Fm.	0	22.3
Foundation		
Clay	0	20.8
Sand	0	33.0
Dawson Fm.	0	15.0
Liquefied Zones		
Upstream	1120	0
Downstream	1120	0

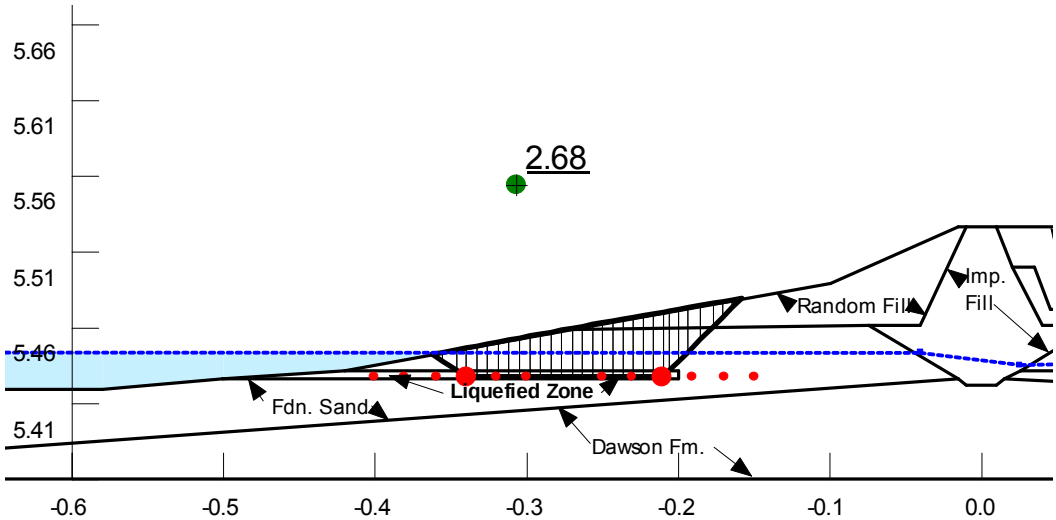

Figure D-1: Post-Liquefaction Slope Stability at Upstream Toe

Figure D-2: Sta 57+60, Pool El. 5444, Upstream Toe

Chatfield Sta 57+60 Pool El 5444 Upstream Toe

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File Information

Revision Number: 21
Date: 09/03/2009
Time: 11:02:31 AM
File Name: Chatfield St 57+60 Pool 5444 - Min Liq - Max S US.gsz
Directory: F:\Projects\Other\Chatfield Dam\
Last Solved Date: 09/03/2009
Last Solved Time: 11:02:42 AM

Project Settings

Length(L) Units: feet
Time(t) Units: Seconds
Force(F) Units: lbf
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D

Analysis Settings

Chatfield Sta 57+60

Kind: SLOPE/W
Method: Spencer
Settings
- Apply Phreatic Correction: No
- PWP Conditions Source: Piezometric Line
- Use Staged Rapid Drawdown: No

SlipSurface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Block
- Critical slip surfaces saved: 1
- Optimize Critical Slip Surface Location: No

FOS Distribution
- FOS Calculation Option: Constant

Restrict Block Crossing: No

Advanced
- Number of Slices: 30
- Optimization Tolerance: 0.01
- Minimum Slip Surface Depth: 0.1 ft
- Optimization Maximum Iterations: 2000
- Optimization Convergence Tolerance: 1e-007
- Starting Optimization Points: 8
- Ending Optimization Points: 16
- Complete Passes per Insertion: 1
- Driving Side Maximum Convex Angle: 5 °
- Resisting Side Maximum Convex Angle: 1 °

Materials

Embankment Impervious

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 24.3 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Embankment Dawson

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 22.3 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Embankment Random

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion: 0 psf
Phi: 24.3 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Embankment Pervious

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 36.1 °

Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Sand

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion: 0 psf
Phi: 33 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Foundation Dawson

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion: 0 psf
Phi: 15 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Liquefied Foundation Sand

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion: 1120 psf
Phi: 0 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Limits

Left Coordinate: (-800, 5420) ft
Right Coordinate: (800, 5435) ft

Slip Surface Block

Left Grid
Upper Left: (-400, 5428) ft
Lower Left: (-400, 5428) ft
Lower Right: (-300, 5428) ft
X Increments: 5
Y Increments: 0
Starting Angle: 135 °
Ending Angle: 147 °
Angle Increments: 3

Right Grid

Upper Left: (-250, 5428) ft
Lower Left: (-250, 5428) ft
Lower Right: (-150, 5428) ft
X Increments: 5
Y Increments: 0
Starting Angle: 45 °
Ending Angle: 45 °
Angle Increments: 3

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
	-800	5444
	-40	5444
	25	5435
	800	5435

Critical Slip Surfaces

	Slip Surface	FOS	Center (ft)	Radius (ft)	Entry (ft)	Exit (ft)
1	372	2.68	(-265.492, 5488.97)	92.704	(-158.286, 5479.71)	(-362.646, 5442.71)

Slices of Slip Surface: 372

	Slip Surface	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
1	372	-359.1799	5440.4555	221.1737	504.06889	183.71428	0
2	372	-350.9369	5435.1025	555.20056	1559.0521	651.90882	0
3	372	-343.07975	5430	873.60099	2615.2204	0	1120
4	372	-336.5	5428	998.4	2507.5714	0	1120
5	372	-329.5	5428	998.4	2670.8571	0	1120
6	372	-322.5	5428	998.4	2834.1429	0	1120

7	372	-315.5	5428	998.4	2997.5714	0	1120
8	372	-308.5	5428	998.4	3160.8571	0	1120
9	372	-301.5	5428	998.4	3324.1429	0	1120
10	372	-294.5	5428	998.4	3487.5714	0	1120
11	372	-287.5	5428	998.4	3650.8571	0	1120
12	372	-280.5	5428	998.4	3814.1429	0	1120
13	372	-273.5	5428	998.4	3977.5714	0	1120
14	372	-266.66665	5428	998.39995	4129.9498	0	1120
15	372	-260	5428	998.39995	4271.3998	0	1120
16	372	-253.33335	5428	998.39995	4412.9998	0	1120
17	372	-246.66665	5428	998.39995	4554.4498	0	1120
18	372	-240	5428	998.39995	4696.0498	0	1120
19	372	-233.33335	5428	998.39995	4837.4998	0	1120
20	372	-226.66665	5428	998.39995	4979.0998	0	1120
21	372	-220	5428	998.39995	5120.5497	0	1120
22	372	-213.33335	5428	998.39995	5262.1497	0	1120
23	372	-208	5430	873.59511	4124.2005	0	1120
24	372	-203	5435	561.59602	3456.456	1879.944	0
25	372	-197	5441	187.19474	2937.3217	1785.9533	0
26	372	-189.76165	5448.2385	-264.47634	2351.7998	1527.2767	0
27	372	-181.28495	5456.715	-793.42067	1699.8892	1103.921	0
28	372	-173.9198	5464.08	-1253.0556	1201.382	542.44479	0
29	372	-167.6662	5470.334	-1643.2645	720.84054	325.47198	0
30	372	-161.41255	5476.5875	-2033.4734	240.27641	108.48896	0

Appendix B
Tri-Lakes Water Control Plans

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Water Control Plan Cover Page

Appendix B-1 – Chatfield Water Control Plan

Appendix B-2 – Cherry Creek Water Control Plan

Appendix B-3 – Bear Creek Water Control Plan

WATER CONTROL PLAN COVER PAGE

The Omaha District Water Control and Water Quality Section acquired contingent approval of the Chatfield, Cherry Creek, and Bear Creek Water Control Plans from the Northwestern Division Missouri River Basin Water Management (MRBWM) office. Following the Record of Decision (ROD) and the Water Storage Agreement (WSA) for the Chatfield Reservoir Reallocation Study, the Omaha District Water Control and Water Quality Section will submit a request for final approval for Chatfield, Cherry Creek, and Bear Creek's active Water Control Plans.

Reallocation would not impact the primary flood risk management purpose of Chatfield reservoir. During Tri-Lakes system flood control storage evacuation for Level I (small flood events), as defined in Appendix B – Tri-Lakes Water Control Plans, the reallocation of flood control storage at Chatfield slightly increases releases and affects the timing and duration of releases made from Cherry Creek and Bear Creek though the primary flood risk management purpose for Cherry Creek and Bear Creek is not affected. There is no change to system flood control storage evacuation releases during Level II (large flood events), as defined in Appendix B – Tri-Lakes Water Control Plans. The reallocated flood control storage space of 20,600 acre-feet (10 percent) at Chatfield Reservoir reduces the overall Tri-Lakes system storage percentage for Chatfield Reservoir from 65 percent without reallocation to 63 percent with reallocation. Due to Chatfield reallocation, the percentage of flood control storage space in Level I (small flood events) at Chatfield Reservoir is decreased, and increased in Level I (small flood events) at Cherry Creek and Bear Creek Reservoirs.

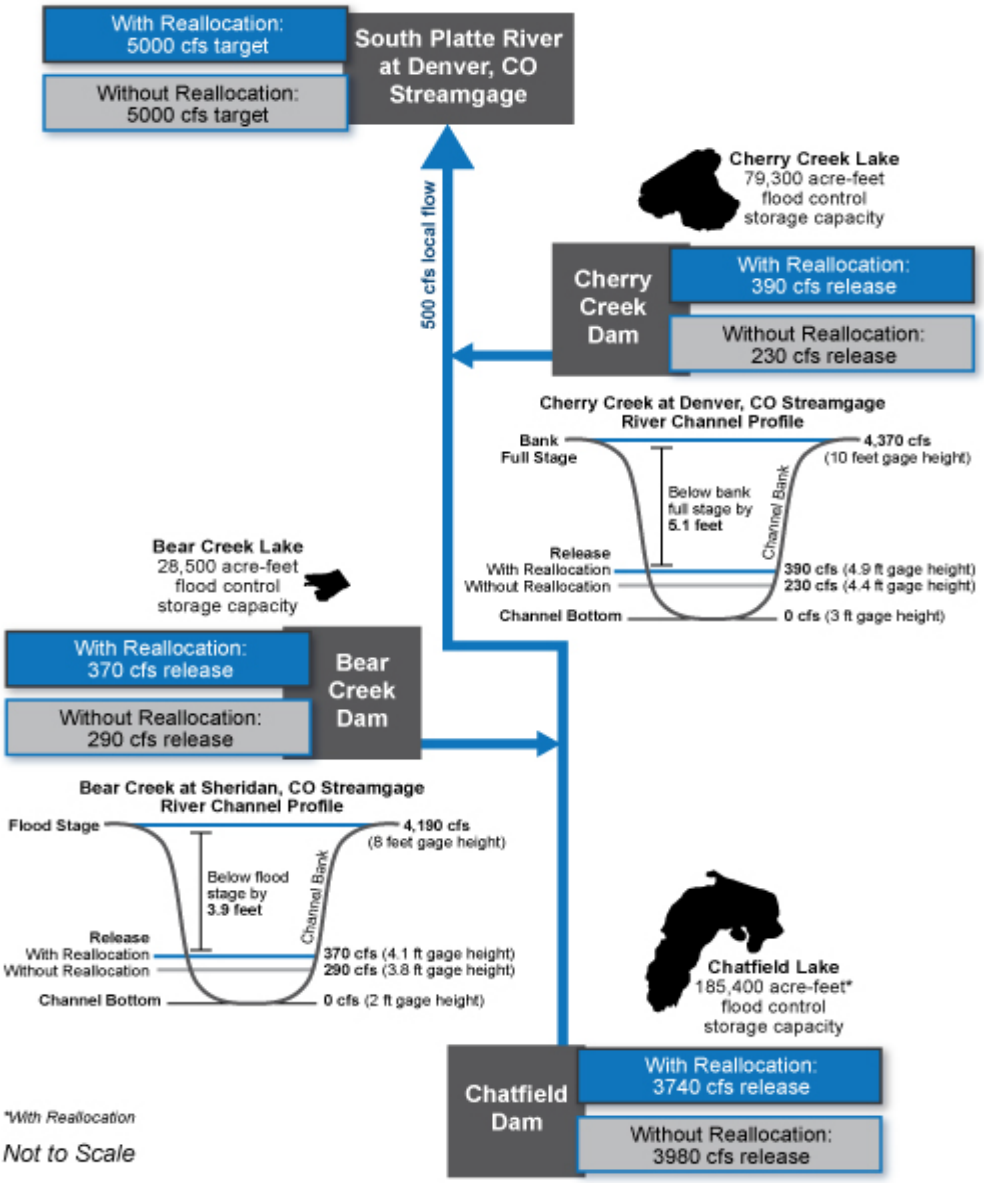
The time to evacuate the system storage during Level I flood events is not increased due to the reallocation nor does it increase the volume of water stored at Bear Creek and Cherry Creek thus it does not increase risk to the Bear Creek and Cherry Creek Dam embankments.

Figure 1 illustrates an example when all three projects are occupying flood control space at the same time. Assumptions for this example are: (1) reservoir inflow at Chatfield is 1500 cfs, at Cherry Creek is 40 cfs and at Bear Creek is 230 cfs (based on average inflow during evacuation of the top 3 reservoir pools), (2) the local flow downstream of the dams is 500 cfs, and (3) the flow target past the South Platte River at Denver, Colorado stream gage is 5,000 cfs. The increase in flood control releases from Bear Creek and Cherry Creek result in stage increases below the dams of less than half a foot. This is 3.9 feet below flood stage on Bear Creek and 5.1 feet below bank full stage on Cherry Creek. These releases are non-damaging, in-channel flows.

Figure 1

Chatfield Reservoir Flood Control Storage Reallocation

Example of Tri-Lakes system flood control storage evacuation for Level I (small flood events)



<u>Relationship between Table 12 of Appendix H and Section 7-05 of Appendix B</u>

The peak releases in Table 12 of Appendix H – Hydrology Report are not relatable to the Tri-Lake system evacuation as outlined in the Chatfield, Cherry Creek, and Bear Creek Water Control Plans in Appendix B – Tri-Lakes Water Control Plans, Section 7-05. Table 12 in Appendix H reflects peak flows that are not coincident with peak releases from all three projects since peak releases from all three projects would not occur simultaneously. Section 7-05 in Appendix B shows the coincident releases from each project, which would not occur during peak flows downstream.

Appendix B-1
Chatfield Water Control Plan

7-01. General Objectives. Engineering Regulation 1110-2-1400, dated 24 April 1970, assigns the Corps of Engineers (Corps) reservoir regulation responsibilities in the Missouri River basin to the Missouri River Division Engineer, now the Northwestern Division Missouri River Basin Water Management (MRBWM) office. This engineering regulation permits delegation of certain reservoir regulation responsibilities to the District Engineer, in whose area the project is located. The responsibilities for assembly and interpretation of data affecting current reservoir regulation and for carrying out routine regulation of Chatfield Reservoir, according to plans agreed on in advance, have been delegated to the Omaha District Engineer. The Division Engineer, through the MRBWM office, monitors and reviews the regulation activities performed by the Omaha District. Plate 9-1 shows the organizational chart for the Omaha District in regards to Chatfield Reservoir regulation.

An agreement between the United States of America and the State of Colorado dated March 1979 describing the state engineer's release responsibility for downstream water rights when Chatfield pool elevation lies between 5423 to 5432 feet can be found in Exhibit II. A separate agreement, dated September 2013, between the United States of America and the State of Colorado also found in Exhibit II, describes the requirements between the agencies within the joint-use flood control and water supply zone (elevation 5432 to 5444 feet).

Chatfield Dam will be regulated for flood control primarily to prevent damage to the metropolitan area of Denver from floods originating on the South Platte River upstream of the dam and will also be regulated to provide for general recreation and fish and wildlife recreation purposes. Project regulation for these purposes is described in the following sections.

7-02. Constraints. The control point for Chatfield Dam regulation is 5,000 cfs at the South Platte River at Denver stream gage. It is important to note that the 5,000 cfs flow target also includes Cherry Creek and Bear Creek Dam releases as well as incremental runoff downstream of each of the dams. Flood control operation is described in detail in section 7-05. Channel capacity varies widely downstream of the dam. Immediately downstream of the dam flows of 5,000 cfs will exceed the South Platte River channel capacity in some areas. Through Denver the channel capacity is much higher, with some locations able to contain flows of 24,000 cfs. Downstream from Denver through the rural areas the natural channel flows wide and shallow and the present channel capacity is less than 5,000 cfs in some high-yield agricultural areas. Protection afforded these areas above and below Denver, therefore, will not be as great as that through Denver. In addition, it would require considerably more storage space to control the reservoir design flood if releases were restricted to less than 5,000 cfs.

Normally, increases in releases should not exceed 500 cfs per day. Release reduction rates should consider downstream impacts. Preferably, releases should be reduced at

a similar rate of 500 cfs per day. However, if a higher rate of change is necessary to accommodate operational circumstances, releases may be increased or reduced at an accelerated rate. The release may even be reduced to a maximum of zero flow in a single gate change if required. Examples of downstream impacts include environmental, water quality, and bank failure. There should be communication with stakeholders if these rates of change will be exceeded.

Unforeseen problems, such as levee breaks and streambank erosion, could limit discharges during flood control operation.

7-03. Overall Plan for Water Control. The normal regulation of Chatfield Reservoir involves responsibilities of the State of Colorado and of the Corps. Refer to Exhibit II for more information.

a. State of Colorado Responsibilities - The State of Colorado will be represented by the Colorado State Engineer. The State Engineer is responsible for administration of all State water laws and accounting for ownership of all water stored in the conservation zone (5385.0-5432.0 feet) of the reservoir. The State Engineer is responsible for satisfying all downstream water requirements below the Chatfield Project, including irrigation and/or water supply diversions, flows for the fish hatchery, and normal river flows. Under normal circumstances the State Engineer will determine what daily river release rates are necessary to meet the downstream water requirements and will issue the necessary regulation release orders directly to the Tri-Lakes Project Office for releases to be made from the conservation pool. However, as determined by the Corps' Omaha District dam safety officer, should any dam safety issues arise, the Corps will assume all regulation decisions.

The State of Colorado and the Corps will regulate the joint-use pool (5432.0 – 5444.0 feet) for water supply and flood control, respectively. When reservoir levels are in the joint-use zone, the Corps will operate for flood control purposes when reservoir pool levels are forecasted by the Corps to rise above elevation 5444.0 feet. At that time the Corps may initiate releases to minimize the maximum reservoir pool elevation. If mountain snowpack totals early in the runoff season are high and models indicate a very high runoff during the snowmelt period, it may be prudent to maintain the pool level lower than 5444.0 feet in anticipation of high runoff and possible flood control releases.

Tri-Lakes Project Office personnel will make all gate changes to valves physically located before the stilling basin, which include the east and west service and low flow gates in the outlet works. At the discretion and under the supervision of the State Engineer, personnel of the irrigation and/or water supply districts may perform the physical operation of the outlet gate valves at their impact basins to supply water directly from the reservoir to their respective water supply ditches. The Colorado

Division will control their releases to the planting base at the valve located at the connection to the 54 inch irrigation pipe. The State Engineer will monitor and control the amount of water taken by each ditch. The State Engineer will be responsible for maintaining up-to-date stage-discharge tables for downstream reservoir river release flow and for providing those tables to the Corps on a timely basis so that the Corps can maintain accurate monthly reservoir reports. The State Engineer through the canal operating agency will furnish the Tri-Lakes Project Office with the daily canal discharge. Further responsibilities of the State Engineer are presented in the operating agreement between the State Engineer and the District Engineer, Exhibit II.

b. Corps of Engineers Responsibilities - The operation of Chatfield Reservoir involves two units of the Corps Omaha District as described in sections 7-03-b-1 and 7-03-b-2 below. Plate 9-1 shows the organizational chart for the Omaha District in regards to Chatfield Reservoir regulation. Additional responsibilities of the Corps are also outlined below.

(1) Water Control and Water Quality Section, Engineering Division. The Omaha District, Water Control and Water Quality Section is responsible for matters pertaining to the regulation of the reservoir. This office prepares the official forecasts for the Corps. Throughout the year the Water Control and Water Quality Section monitors reservoir releases made from the conservation and joint-use pools by the State Engineer. When the pool level is in or forecasted by this office to enter the exclusive flood control pool, this office is responsible for scheduling reservoir releases to attain optimum flood control benefits and control of project storage to assure regulation in conformance with the authorized functions of the project. The Water Control and Water Quality Section is responsible for procurement of necessary snow pack, precipitation, streamflow, and reservoir elevation data, while also making advanced estimates of streamflow from snow cover and/or rainfall reports for regulation purposes and to alert field operating personnel of potential flood occurrences. The Water Control and Water Quality Section prepares the monthly reservoir report (MRD Form 0168) for Chatfield Reservoir, which contains the official daily elevation, inflow, and outflow, see Plate 9-2. Issuance of reservoir regulation orders as outlined in section 7-03-b-4 is also performed by the Water Control and Water Quality Section.

(2) Tri-Lakes Project Office, Operations Division. The Operations Division plans and directs the maintenance and physical operation of the project. They establish the standards of maintenance and provide proper staffing of operating personnel at the Tri-Lakes Project Office to accomplish these objectives. The Tri-Lakes Project Office staff performs all gate changes at Chatfield Dam. This office has agreed to initiate email or telephone correspondence for reservoir releases in excess of 1500 cfs or an increase in release of more than 500 cfs with the Urban Drainage and Flood Control District, a local agency that coordinates releases with local county emergency managers.

(3) Flood Period Organization. The normal organization of the Omaha District is somewhat modified during a flood period to cover the additional duties made necessary by the flood emergency. These duties are to: 1) operate the flood control reservoirs for maximum risk mitigation; 2) collect and disseminate flood information; 3) protect Corps of Engineers' property and works; 4) obtain engineering data; and 5) in extreme emergency, assist in relief and rescue work. These activities take precedence over normal work and are performed by those employees of the District who have been trained for specific emergency duties. In case of purely local flooding in a reservoir controlled basin, such as Chatfield or Cherry Creek, only those units of the District Organization concerned with the normal operation of the reservoir are placed in an emergency status. A directory of regulation personnel is shown in the Standing Instructions to the Dam Tender, Exhibit I.

(4) Regulation Orders. When it is the responsibility of their respective offices as indicated in section 7-01, the State Engineer and the Omaha District Water Control and Water Quality Section will issue regulation orders directly to the Tri-Lakes Project Office. All requests for regulation of project releases, other than regulation responsibilities of the State Engineer, will be referred to the Water Control and Water Quality Section for approval and issuance of orders. All regulation orders will normally be issued verbally and then confirmed in writing as official signed orders as soon as possible. An official reservoir regulation order will be issued in writing by the Water Control and Water Quality Section for all gate changes made at Chatfield Dam, those initiated by the State Engineer and otherwise. Tri-Lakes Project Office personnel will record the gate setting for each gate change in the pool report spreadsheet, which can be accessed by the Water Control Manager to complete the written order. A copy of all orders issued by the Water Control and Water Quality Section will be furnished to the State Engineer and the Tri-Lakes Project Office. Under normal circumstances this copy will contain a brief statement giving the background and reasons for issuance of the order. In the case of a dam safety issue or major flood control release, the signed reservoir regulation order should contain sufficient details to describe the reasoning of the reservoir regulation decision. In the case of a deviation from the water control plan, the reservoir regulation order should note that a signed deviation approval from the MRBWM office has been acquired.

(5) Emergency Organization. It is not anticipated that any emergency organization other than described in section 7-03-b-3 will be required. However, under the provisions of the Standing Instructions to Dam Tender, reference section 7-04, communication failure during a flood event may result and isolate the dam tender, thus making that person the sole project operating organization.

(6) Coordination with Other Agencies. Daily project operating data and miscellaneous hydrologic information will be exchanged between the Project Office, the

State Engineer and the Water Control and Water Quality Section. Cooperation is also maintained with the U.S. Geological Survey and Colorado Division of Water Resources relative to the collection and reporting of precipitation amounts, stream stages, and discharge. The Natural Resources Conservation Service provides snow pack and runoff forecasts, and the National Weather Service provides precipitation and stream gage forecasts.

(7) Communication. Telephone and email facilities are presently available for communication between the Project Office, State Engineer, and Water Control and Water Quality Section. In event of loss of these means of communication, the dam tender may communicate via vehicular travel between the respective offices noted above and/or via cellular phone.

7-04. Standing Instructions to Dam Tender. Exhibit I contains the Standing Instructions to Dam Tender. The Standing Instructions to the Dam Tender provide detailed instructions for regulation of project releases and storage under emergency conditions, such as communication failure. This failure may result and isolate the dam tender, thus making that person the sole project operating organization. Regulation orders issued verbally will be confirmed in writing as official signed orders as soon as possible.

7-05. Flood Control. Chatfield Dam and Reservoir will be regulated for flood control to mitigate risk to the metropolitan area of Denver from floods originating on the South Platte River upstream of the project location.

In general, the developed method of flood control regulation of Chatfield Reservoir may be classified as Method C, defined in EM 1110-2-3600. This represents a combination of the concept of reducing downstream damaging stages as much as possible during each flood with the currently available storage space, with consideration of control of floods of project design magnitude.

The Corps and the State of Colorado will regulate the joint-use pool (5432.0 – 5444.0 feet) for flood control and water supply, respectively. When reservoir levels are in the joint-use zone, the Corps will operate for flood control purposes when reservoir pool levels are forecasted by the Corps to rise above elevation 5444.0 feet. At other times the State of Colorado will regulate for water supply purposes. The Corps will issue a snow melt runoff inflow forecast to the State of Colorado in the event of an above normal snowpack. An annual teleconference or face-to-face meeting will be scheduled in February to discuss the flood outlook due to snow melt runoff.

If the Corps forecast indicates that Chatfield Reservoir will rise above 5444.0 feet due to snowmelt or rainfall runoff the Corps will contact the State of Colorado and follow-up in writing. At that time the Corps may initiate releases to evacuate all or a percentage

of the joint-use storage space to minimize the maximum reservoir pool elevation.

The Corps shall ultimately determine the percentage of the joint-use space to be evacuated for the purpose of flood control. This amount will be communicated with the State of Colorado. The Corps will not assure refill of the joint-use storage space released downstream for flood control purposes. Flood storage evacuation of Chatfield Reservoir must be coordinated with Cherry Creek and Bear Creek Reservoirs. Regulation plans are given in the following paragraphs.

a. Rising Pools/Flood Inflow Period. During flood inflow periods and/or rising pool levels, Chatfield, Cherry Creek, and Bear Creek Reservoirs will be regulated to assure safe control of each flood event. Releases from the dams will be based on forecasted and observed inflows and pool levels as well as downstream flows. During periods of forecasted flood inflows or while the pool level is in the flood control zone, releases will generally be kept as large as possible to meet the 5,000 cfs target at the South Platte River at Denver stream gage . This target includes releases from Chatfield, Cherry Creek, and Bear Creek Dams as well as incremental runoff below the dams. Releases from the three dams from the forecasted flood onset to the complete evacuation of flood storage will be at the discretion of the Water Control and Water Quality Section.

The normal allowable increase in releases at Chatfield Dam is 500 cfs/day. There have been many occasions when the daily change in releases exceeded the normal maximum of 500 cfs/day with largest being 1170 cfs/day in May 1984. The maximum outlet works discharge capacity from Chatfield is 8300 cfs at a pool elevation of 5500 feet. The historic maximum release from Chatfield, at the time of publication, was 3350 cfs in July 1995.

b. Design Assumptions for Flood Control Storage. Rainfall runoff from major storm events occurs so rapidly in this area that a shortened time window is afforded for thoroughly evaluating downstream flood conditions. In order to provide the best downstream flood control, in the reservoir design of Chatfield and Bear Creek Projects, no releases were planned during flood events. The original design was based on experience in operating Cherry Creek Reservoir. Chatfield Project design storage was based on releasing no water for five days after the heaviest portion of the rainfall, then initiating a release of 500 cfs and increasing releases of 500 cfs a day until a release of 5,000 cfs was achieved. This design assumes no releases from Bear Creek or Cherry Creek and no incremental runoff downstream of the projects to the control point, the South Platte River at Denver stream gage. Bear Creek Project design storage was based on releasing no water for two days, then progressively increasing releases as the flood pool was filled, to a maximum of 1,500 cfs. Cherry Creek Reservoir was designed to store all flood inflows, but studies are underway evaluating the adequacy of Cherry Creek Reservoir’s storage during large rain events.

With the top of the joint-use zone at elevation 5444 feet, the maximum pool elevation during the Reservoir Design Flood (RDF) does not stay below the spillway crest (elevation 5500 feet) when using the original design criteria of a 5-day shutdown period with a 500 cfs per day stepped-release. Alternative design criteria for reservoir operations included a) a shutdown period adjusted to 2 days while the stepped-release remained 500 cfs per day and b) a shutdown period at 5 days and increased the stepped-release to 1,300 cfs per day. During the RDF both alternatives resulted in a maximum pool elevation below the spillway crest, see Figure 7-1 and 7-2. Both alternatives are considered acceptable design assumptions; reference the "Antecedent Flood Study, Tri-Lakes Reallocation Feasibility Study, December, 2005" and the "Impact of Storage Reallocation on Reservoir Releases at the Chatfield Dam near Denver, CO, November 2010".

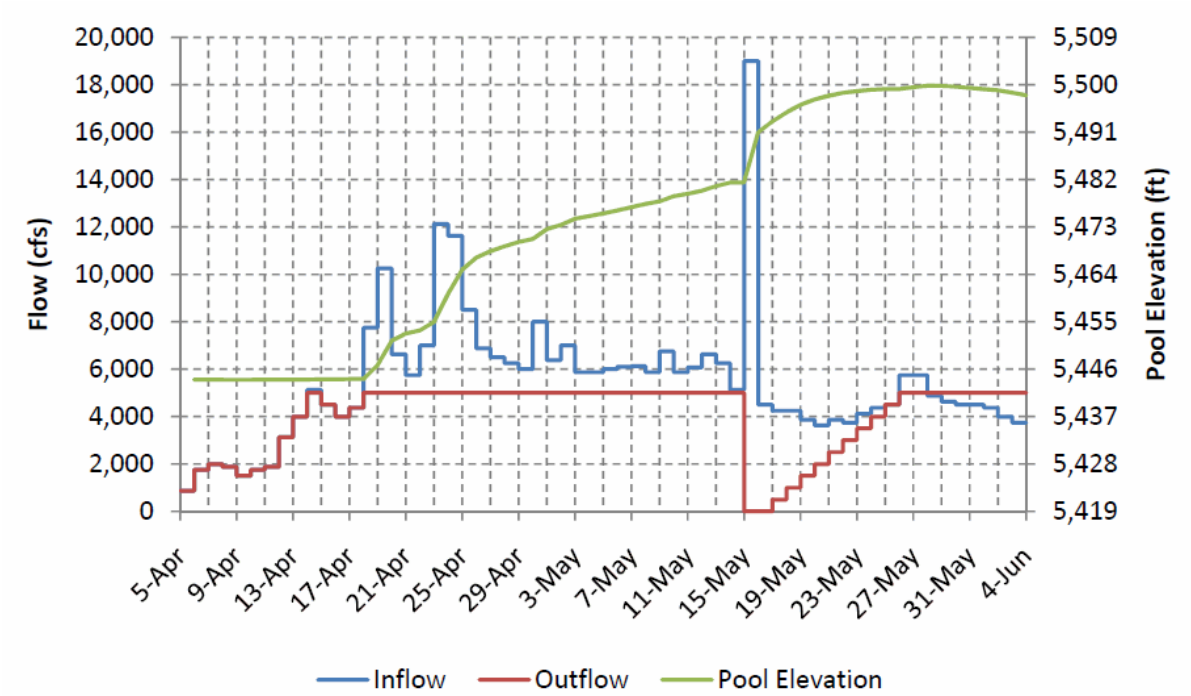


Figure 7-1: RDF pool elevations with a starting elevation of 5444 feet using the 1998 capacity, a 2-day shutdown period, and a 500 cfs per day stepped-release.

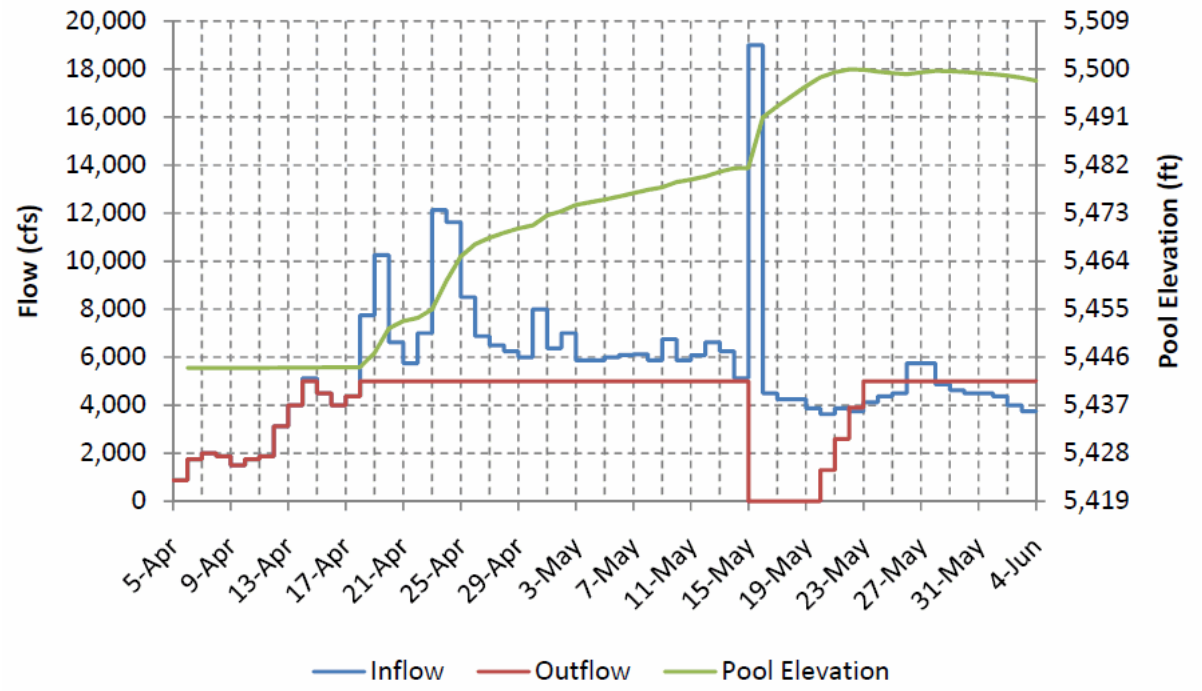


Figure 7-2: RDF pool elevations with a starting elevation of 5444 feet using the 1998 capacity, a 5-day shutdown period, and a 1,300 cfs per day stepped-release.

During flood control operations, the primary consideration in determining reservoir releases will continue to be keeping releases as large as possible to meet the 5,000 cfs target at the South Platte River at Denver stream gage. However, consideration will also be given to the design assumptions for the shutdown period and rate of stepping up releases. This will ensure adequate capacity for the Chatfield Reservoir to control the Reservoir Design Flood without uncontrolled spillway releases or compromising flood control benefits downstream.

c. Surcharge Storage. The surcharge storage zone at Chatfield reservoir includes reservoir pool levels between the spillway crest elevation of 5500.0 feet and the maximum pool level of 5521.6 feet. For large flood events that cause reservoir pool levels to rise above the spillway crest elevation, it is expected that Chatfield Reservoir will be making a high release of up to 5,000 cfs from the outlet works. As the reservoir levels rise above the spillway crest, the releases from the outlet works may be reduced so that the combined flow from the outlet works and spillway is still within the 5,000 cfs target at the South Platte River at Denver stream gage. At reservoir pool elevations above 5502.1, the spillway flow alone would be 5,000 cfs or higher and the outlet works release may be set at zero under those conditions. After the reservoir pool level peaks and pool levels fall to near the spillway crest, outlet works releases may be increased to meet the 5,000 cfs target at the South Platte River at Denver stream gage.

d. System Operating Plan for Flood Storage Evacuation. The following paragraphs describe the system regulation plan for flood storage evacuation in the Tri-Lakes projects when more than one project has storage in the flood control pool. If Bear Creek and Cherry Creek have empty flood control pools, Chatfield's flood control storage will be evacuated to pool elevation 5444 feet with releases to target 5,000 cfs at the South Platte River at Denver stream gage. The normal allowable rate of increase in releases at Chatfield Dam is 500 cfs/day.

System or coordinated regulation of Cherry Creek, Chatfield, and Bear Creek Reservoirs will be necessary only after flood flows have entered the reservoirs and during flood storage evacuation. When water has accumulated in the flood storage zones of these projects, an equal protective balance of flood storage kept vacant should be maintained during pool evacuation. This balance is based on establishing an equal risk in each project of filling the remaining flood control space from a similar subsequent flood. The storage remaining should provide equal protection at each project against runoff from rainfall of standard project flood magnitude. Flood storage evacuation will continue at Chatfield Dam until the pool elevation falls to 5444 feet, at which time coordination will resume with the State Engineer.

Two storage levels are established in each project. Generally, the upper Level II of storage space approximates the volume of the rainfall standard project flood. In Chatfield, Level II amounts to 160,000 acre-feet (af), the volume of the rainfall standard project flood. As the entire flood control space in both Cherry Creek and Bear Creek Reservoirs was designed mainly for protection from the sudden occurrence of a rainfall standard project flood and not from the longer duration mountain snowmelt flood, 95 percent of this space was assigned to Level II. The remaining five percent of flood storage space in Cherry Creek and Bear Creek Reservoirs is allotted a lower evacuation rate at the downstream control point, the South Platte River at Denver stream gage. This space was assigned to Level I to provide for a transition from flood releases to conservation releases and to lessen unnecessary slugging of high releases for small encroachments into the flood pools. The lower evacuation rate of the five percent of storage will not significantly affect the project flood control function. However, since individual design criteria for both the Chatfield and Cherry Creek Projects were based on releasing 5,000 cfs out of each project and not a target of 5,000 cfs at the South Platte River at Denver stream gage, which includes incremental runoff and releases from Chatfield, Cherry Creek, and Bear Creek following the flood peak, strict adherence to these evacuation criteria should be followed. Tables 7-1 and 7-2 present a tabulation of storage in the three projects assigned to each level and desired evacuation flow to be targeted at the control point, South Platte River at Denver stream gage, depending on storage level, percent of storage space filled, and time of year. This system procedure is also presented in the Water Control Manuals for Cherry Creek Dam and Reservoir and Bear Creek Dam and Reservoir.

Table 7-1 lists the storage and elevations based on the following surveys: Cherry Creek (2007), Chatfield (2010), and Bear Creek (2009).

Table 7-1
FLOOD REGULATION STORAGE LEVELS

	Level I			Level II		
	Elevation (feet)	Storage (AF)	Incr. Storage (AF)	Elevation (feet)	Storage (AF)	Incr. Storage (AF)
Cherry Creek	5550.0	12,600		5554.4	16,500	
	to 5554.4	16,500	3,900*	to 5598.0	91,900	75,400
Chatfield***	5444.0	47,700		5455.3	73,100	
	to 5455.3	73,100	25,400**	to 5500.0	233,100	160,000
Bear Creek	5558.0	1,800		5569.2	3,300	
	to 5569.2	3,300	1,500*	to 5635.5	30,300	27,000

* 5 percent of total flood pool
** Total Flood Control Storage (233,100 af) minus 47,700 af = 185,400 af; 185,400 af minus Standard Project Rainfall Flood (160,000 af) = 25,400 af

*** Flood Control pool in 1973 Chatfield Preliminary Reservoir Regulation Manual indicates the base of the flood control pool at elevation 5430.0 feet. The base of the flood control pool was changed to 5432.0 feet in March 1979 (see Exhibit II, Memorandum of Understanding between COE and State of CO). The base of the exclusive flood control pool was changed to 5444.0 feet in 2013 (see Exhibit II, Memorandum of Understanding between COE and State of CO) in response to the reallocation of flood control storage to joint-use flood control and water supply.

Note: Based on area/capacity surveys from 2007 for Cherry Creek, 2010 for Chatfield, and 2009 for Bear Creek.

Table 7-2
DESIRED CONTROLLED FLOW TARGET - DENVER STREAM GAGING STATION

April - July:

Any Reservoir at Level II - 5,000 cfs
All Reservoirs at Level I, with one or more, more than 50% filled - 5,000 cfs
All Reservoirs at Level I, and all less than 50% filled - 4,000 cfs

August – March

Any Reservoir at Level II - 5,000 cfs
All Reservoirs at Level I, with one or more, more than 50% filled - 4,000 cfs
All Reservoirs at Level I, and all less than 50% filled - 3,000 cfs

Water will be released from the reservoir with the highest percent of storage in the highest level occupied until the storage balance or the percent of storage filled, for the

same level, is the same in all reservoirs. Plate 7-3 displays the parallel reservoir balance for the three projects in percent of storage space filled for the two levels.

When all three reservoirs have the same percentage of storage in the same level, equal balance has been achieved. For example, all reservoirs are in balance at 50% full in Level II at the following cumulative storage levels: Chatfield, 153,000 af; Cherry Creek, 54,000 af; Bear Creek, 16,800 af. Table 7-3 gives the parallel reservoir balance for the three projects in percent of storage space filled for the two levels based on the amount in the incremental storage column for each level as shown in Table 7-1. When all reservoirs have the same remaining balance of storage, the storage should be kept in balance or the percent of storage filled should be kept the same until all water is evacuated. Table 7-3 shows percent of storage depletion required out of each reservoir to enable continued parallel reservoir balance for all combinations of the three projects that may contain storage. For example, a total of 100 af of flood control storage occupied among the Tri-Lakes projects would reflect an equal balance for Level I - Balance Combination C when Bear Creek had no flood control storage, Chatfield had 87 af (87%) of storage, and Cherry Creek had 13 af (13%) of storage.

TABLE 7-3
UPPER SOUTH PLATTE RESERVOIR SYSTEM
PERCENTAGE OF STORAGE DEPLETION REQUIRED OUT OF EACH RESERVOIR TO ENABLE A CONTINUED PARALLEL RESERVOIR BALANCE
(Values are in percent)

LEVEL II (see Table 7-1 for Elevations)			
Balance Combination	Chatfield	Bear Creek	Cherry Creek
A	61	10	29
B	86	14	0
C	68	0	32
D	0	26	74
LEVEL I (see Table 7-1 for Elevations)			
Balance Combination	Chatfield	Bear Creek	Cherry Creek
A	82	5	13
B	94	6	0
C	87	0	13
D	0	28	72

Following is an example illustrating how an equal parallel reservoir balance is maintained during storage evacuation using Table 7-3. This example assumes (1) all three reservoirs are in an equal balanced condition as indicated by balance combination A of Level II of Table 7-3, (2) a control point flow of 5,000 cfs is targeted at the South Platte River at Denver stream gage, and (3) there are no downstream channel constraints below the three projects. Values tabulated are average daily flows in cfs. After the total release on line 3 is determined, the estimated inflow into the three projects is totaled on line 4. The difference between this total on line 4 (inflow) and line 3 (release needed from 3 projects) represents the total storage depletion from the 3 projects on line 5. Table 7-3 is utilized to determine what percent of this storage is required out of each reservoir to enable a continued parallel reservoir balance. The difference between the estimated inflow and storage depletion for each project represents the required release from that project. The total release from the 3 projects represents the required total release needed to target the desired flow at the South Platte River at Denver stream gage, with an allowance for incremental flow. A release of 1 cfs over a 24 hour period is equivalent to 2 af of storage.

1. Desired flow at South Platte River at Denver Stream Gage							5,000
2. Incremental flow* between 3 projects and Denver Gage**							500
3. Total release needed from 3 projects							**4500**
		Chatfield		Bear Creek		Cherry Creek	Total
4. Estimated inflow**		1,100		0		100	1,200
5. Storage depletion***	(61%)	2,000	(10%)	300	(29%)	1,000	3,300
6. Required release		3,100		300		1,100	**4,500**

* Incremental flows are flows that enter the stream downstream of dam releases
** Values to be estimated
*** Values from Table 7-3

e. Regulation Schedule. Regulation rule curves for flood control regulation on Plate 7-2 were developed by methods described in section 4-05 of EM 1110-2-3600, primarily for use during large floods or during emergency regulation. The rule curves will serve as a basis for regulation when other information may not be available. The rule curves are based on a rainfall runoff recession. The curves display the minimum releases for any combination of pool elevation and recession inflow, to assure effective use of the total flood control storage by 1) filling the remaining flood control storage, 2) reducing the maximum flood release, and 3) reducing the magnitude of changes in release rates. As these release rates are minimum values, actual flood control release rates will be kept as large as feasible, to meet the 5,000 cfs target at the South Platte River at Denver stream gage.

7-06. Recreation. The demand for water-based recreation near the large metropolitan city of Denver is substantial. The Chatfield Project satisfies part of the demand. The sediment pool serves as the recreation pool. In order to initially fill the

sediment pool, local interests agreed to allow storing of water for recreation, recognizing the eventual depletion effects of the sediment pool. In this respect, the Governor of Colorado, by letter of intent, obligated the State to provide sufficient water to fill the reservoir to the multi-purpose pool elevation of 5432.0 feet and to replace annual evaporation losses. The joint-use storage space between 5432 feet and 5444 feet will be operated for multiple purposes, which include flood control, recreation, fish and wildlife, and water supply. The Omaha District will operate this zone for flood control purposes when the reservoir levels are forecasted by the Corps to rise above 5444 feet, see section 7-05 for flood control regulation requirements.

The Corps will continue to maintain a closely coordinated planning effort with the State of Colorado, Department of Natural Resources, and Colorado State Parks. The Corps constructed recreational areas upstream from the dam that the State of Colorado leases, operates, and maintains for recreation use. Visitation to the Chatfield Project grew from 288,000 in 1976 to approximately 5,240,000 visits per year in FY01 through FY10.

The City of Littleton and South Suburban Recreation and Park District developed the recreation facilities along the South Platte River channel in the portion of the project downstream from the area acquired for Chatfield Dam and Reservoir with Federal financial assistance.

7-07. Water Quality. On-going urbanization will impact Chatfield Reservoir water quality, which in turn could impact future releases. Refer to section 4-08 for water quality information.

The Chatfield Basin Water Quality Authority maintains an on-going program that involves water quality monitoring and management of some upstream activities such as sewage treatment.

7-08. Fish and Wildlife. Fish and wildlife is an authorized project purpose at the Chatfield Project.

The basic premise of the flood control aspect of the water control plan is to release stored waters in the flood control zone of the reservoir as soon as possible following inflow from a flood event. This premise may be consistent with management of the fish and wildlife resources of the project as it reduces to a minimum the possible impacts to aquatic and terrestrial wildlife and habitat.

During the 1980's some temporary storage in the flood control zone of Chatfield Reservoir occurred at least once during every year. However, most of the years the water was less than three feet above 5432.0 feet, the base of the previous exclusive flood control and top of conservation pool, and the flood storage was of very short

duration. In only two of the years did flood storage exceed five feet above 5432.0 feet, the base of the previous exclusive flood control and top of conservation pool. In those two years the storage period was brief; stored water was released as soon as downstream conditions allowed. The shoreline vegetation is relatively tolerant of short periods of inundation so that the shallower, short duration flood events may not cause permanent damage. Longer duration events, however, may result in adverse impacts to shoreline vegetation. Inundation of shoreline and upland vegetation for periods longer than two to three weeks would either seriously injure or kill most of the vegetation as did happen in 1995. In such cases, barren mudflats may occur and a period of succession would ensue that could take several years before the vegetation returned to pre-flooding conditions. The areas also could be seeded or sodded and weed control will be an issue.

Because Chatfield Reservoir is a relatively shallow, plains reservoir, it is primarily a warm-water fishery. Normal operations and normal springtime floodwater inflows would have little effect on the fishery from a water temperature standpoint. Flood inflows could, however, have a temporary negative impact on the lake fishery if high inflows in suspended solids cause the water to become turbid. High turbidity reduces light levels in the lower depths of the lake and interferes with oxygen transfer (breathing) in the aquatic life forms in the lake. As temporary storage increases water residence time, suspended solids will tend to settle out. Settling of particulates may result in the surface waters becoming less turbid, but degradation of organic matter associated with settling particles may deplete oxygen in deeper waters while burial of bottom dwelling organisms may increase sediment oxygen demand.

The outlet works have only a single level for releases. Thus it is not possible to mix water from multiple levels to manage for a particular species of fish.

Chatfield Reservoir is not a primary waterfowl habitat area. It is not on a major migration flyway and it lacks the vegetation and cover necessary for it to be an important stopover point during spring or fall migration. Some local nesting of a few common waterfowl species likely occurs at the project. Larger numbers of Canada Geese use the reservoir as a roosting area in the fall and winter. Normal flood control operations would not be expected to have any significant impacts on such waterfowl nesting.

The U.S. Fish and Wildlife Service (F&WS) has responsibility for oversight of the Endangered Species Act. The F&WS maintains that temporary storage of floodwaters in upstream reservoirs may have impacts on species that depend on the Platte River downstream for part of their life requisites. The federal agencies that are responsible for manipulations of the Platte River system upstream are said to have some responsibilities for protection of those downstream species. The problem is complex; the major elements to it follow:

a. Detention of upstream floodwaters in upstream reservoirs reduces the peak and the overall volume of the effects the flood would otherwise have on downstream areas. The Platte River in Nebraska, for instance, no longer is impacted by heavy and prolonged spring flooding that once periodically scoured the channel and kept trees from gaining a foothold. Where the channel was once wide, shallow, and relatively treeless, it is now narrower, deeper, and heavily tree-covered in many areas. Each upstream reservoir adds to the situation in a cumulative manner.

b. The main species of concern on the central Platte River in Nebraska are the whooping crane, least tern, pallid sturgeon, and piping plover. All of these species have been designated as federally threatened or endangered. Upstream impoundments and increased depletions from the Platte River have adversely influenced habitat for these downstream species because they have changed the timing and volume of flows. These adverse impacts have accumulated over the past 40 years or more, and continue to influence the flood plain environment.

c. The South Platte Watershed within and upstream of Chatfield Park is designated as critical habitat for the Preble's Meadow Jumping Mouse. In the last century, widespread habitat loss and fragmentation due to development, water diversions, overgrazing, water pollution, and gravel and sand mining resulted in a rapid decline of the already rare Preble's populations. It is currently listed as a threatened species in Colorado by both the State and Federal government. Implementation of the joint-use zone (5432-5444 feet) may adversely impact the Preble's habitat if operation of the joint-use zone results in damage to shoreline, wetland or riparian habitat.

7-09. Water Supply. Denver Water, through a 1979 contract with the Colorado Water Conservation Board and Colorado State Parks, is entitled to the use of 11,134 af of storage in Chatfield Reservoir from elevation 5423 to 5,432 feet. Denver Water's use of the storage is subject to conditions in the 1979 contract for maintaining water levels for recreation. Under the terms of the 1979 contract, Denver Water commits to use best efforts to keep the reservoir above 20,000 af (current elevation 5,426.32 feet) from May 1 to August 31 of each year. Denver Water cannot lower the reservoir below elevation 5,423 feet except during severe and prolonged drought conditions as determined by the Colorado Water Conservation Board and agreed to by the Corps. In 2013, the Chatfield Reallocation FR/EIS was finalized. See Exhibit II, for the agreement between the Corps and the State of Colorado, dated September 2013, describing the requirements between the agencies within the joint-use flood control and water supply zone (5,432 and 5,444 feet). See section 7-05 for flood control regulation requirements.

The City Ditch is a carrier ditch that is currently owned and operated by the City of Englewood. It was constructed in 1860 and its original dimensions were approximately

10 feet wide and 20 feet wide at the channel bottom and top of bank, respectively. The original head gate for the diversion of flow from the South Platte River was located near the headwaters of the Chatfield Reservoir conservation pool at about elevation 5425.0 feet. The water rights embodied in the City Ditch diversions are some of the earliest in the area. The current diversion for the City Ditch is through the Chatfield manifold. The ditch has been piped except for some short sections within Englewood. In 2002, the ditch was terminated at the Interstate 25 crossing in Denver, so the northern terminus for the ditch is now a blow-off device near Harvard Gulch in Denver. Being a carrier ditch, it serves customers with raw water in much the same manner as treated water customers are served from a pressure main.

The Plum Creek Pump Station is located on the north side of State Highway No. 75 between City Ditch and the South Platte River. Its purpose is to convey raw water diversions from City Ditch and lift them from elevation 5400.0 feet to 5570.0 feet for further distribution. The development consists of a diversion structure on City Ditch and an earthen stilling reservoir as a source of supply for the suction header serving lift pumps. At the reservoir, a frame structure is located over the inlet control. The pump station was constructed in 1955 and has been well maintained. The intake and pumping plant are below elevation 5426.0 feet.

The Last Chance Ditch is operated as an irrigation and water supply ditch by stockholders owning shares in the Last Chance Ditch Company No. 2. At the inception of the Chatfield Project, the stock list included 31 individual owners of which the City of Aurora owned a controlling interest of about 50.1 percent of the stock. Other municipal owners are Denver Water and the Centennial Water and Sanitation District. The original head gate was located just upstream from the Denver Water's former Kassler Water Treatment Plant and just within the upper limits of the Chatfield Reservoir flood control pool. The current diversion is through the Chatfield manifold to the Last Chance control valve near C-470. The City of Aurora diverts its Last Chance Ditch shares through its intake at Strontia Springs Reservoir.

The Nevada Ditch is a combination irrigation and carrier ditch largely owned by the municipalities of Denver, Englewood, and Littleton. Stock records show 260 shares outstanding, of which about 92 percent are owned by the three cities and the rest by individuals. The former diversion point was in the Chatfield Dam embankment area. The head works and ditch facilities were badly damaged in the 1965 flood but have since been rebuilt. Ditch facilities were damaged again by high flows during May of 1969 but have since been restored to service. Current diversion is through the Chatfield manifold to the Nevada control valve near C-470.

The Chatfield State Fish Unit (SFU) was constructed as a component of the required mitigation due to the original construction of Chatfield Reservoir. The SFU is not operated as a full scale hatchery, as was originally intended, due to the lack of a

reliable water supply. The SFU does have decreed water rights for the operation of the facility. However, when Denver exercises its more senior Chatfield Reservoir storage and exchange rights, flows through the SFU can be shut off. Therefore the SFU is currently operated as holding facility for fish that have been hatched and reared at other locations. These fish are eventually stocked in streams and lakes primarily within the Denver Metro area. When water is available, it is delivered via the 54 inch pipeline that also serves the City and Nevada Ditches. The Corps has allocated 30 cfs of the pipeline capacity to the Division of Wildlife for use at the SFU. If reliable water could be secured, the facility could still be expanded into a full sized hatchery, potentially for both warm and cold water production. This would be an important asset to the Division and the region as population increases and new water projects will increase the demand for fish stocking, particularly in and near the Front Range. At this time it is unknown whether the reallocation of storage space in Chatfield Reservoir will augment or further reduce the available water supply to the SFU.

a. Future Development. The continued growth of the need for water for domestic, irrigation, and industrial uses will tend to assure the further development of water supplies for use in the South Platte River basin.

7-10. Hydroelectric Power. None at this project.

7-11. Navigation. None at this project.

7-12. Drought Contingency Plans. No plan has been developed at this time. Guidance concerning the development of drought contingency plans is being reviewed and updated. A drought contingency plan for Chatfield Dam and Reservoir will be coordinated with stakeholders following the approval of the updated guidance.

7-13. Flood Emergency Action Plans. Normal flood regulation of the Chatfield Reservoir is accomplished by specific regulation orders to the Tri-Lakes Project Office from the Omaha District Water Control and Water Quality Section. However, it is conceivable that communication may be disrupted between these offices at times when project events may require changes in existing regulation instructions in order that the project may more properly perform its authorized function. In order that the Tri-Lakes Project Office may have appropriate information and instructions for modifying existing regulation orders, a procedure has been developed to guide the project in determining project operations under such an emergency. This procedure is given under the Emergency Regulation part of the Standing Instructions to the Dam Tender, Exhibit I. This procedure is defined to begin with a failure in communications between the Tri-Lakes Project Office and the Omaha District Water Control and Water Quality Section personnel at a time when the reservoir is rising rapidly, high inflows are indicated, excessive rainfall has occurred, flooding below the dam is occurring or appears imminent, or when a combination of any of these is occurring. During such emergency

periods, regulation of project releases will be made by the Tri-Lakes Project Office in accordance with the instructions given in Exhibit I. Continuing efforts will be made to re-establish communications.

7-14. Deviation from Normal Regulation. Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. For example: (1) releases according to the schedule should not exceed downstream channel capacity unless the safety of the dam is in question; or (2) temporary delays of a few days duration in evacuation of flood storage will be considered to mitigate damages and/or for special circumstances downstream. Deviations require prior approval from the Northwestern Division Commander except as noted in section 7-14-a. Requests to deviate from normal regulation of the project fall into one of the categories described below.

a. Emergencies. Deviations from the release schedule will be made if emergency conditions exist upstream or downstream of the dam. Examples of these types of emergencies include dam safety emergencies, downstream chemical spills, drownings, and facility failures. During an emergency activity, the Omaha District will inform the MRBWM office of its activities as soon as possible. Written confirmation of the deviation, including a description of the cause of the emergency, will be furnished as soon as practicable to the MRBWM office as shown in NWDR 1110-2-6.

b. Unplanned Minor Deviations. A deviation is a proposed plan of operations that do not follow the approved water control plan. A typical example of activities that would create the potential for unplanned minor deviations would be modifications of bridge and utility crossings. In evaluating requests for these types of deviations, the Omaha District will consider upstream watershed conditions, potential flood threats, the amount of water in storage at Chatfield Reservoir, and whether any alternative measures could be taken that would not require a deviation. Written request of the deviation and a description of the cause will be furnished to the MRBWM office as shown in NWDR 1110-2-6.

c. Planned Deviations. Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. All conditions such as data on flood potential, lake and watershed conditions, possible alternative measures, benefits to be expected, and probable effects on other authorized and useful purposes will be analyzed. Planned deviations will be coordinated with all appropriate entities, including locals and state offices and a written request will be furnished to the MRBWM office as shown in NWD 1110-2-6.

7-15. Rate of Release Change. Normally, increases in releases should not exceed 500 cfs per day. Release reduction rates should consider downstream impacts. Preferably, releases should be reduced at a similar rate of 500 cfs per day. However, if

a higher rate of change is necessary to accommodate operational circumstances, releases may be increased or reduced at an accelerated rate. The release may even be reduced to zero flow in a single gate change if required. Examples of downstream impacts include environmental, water quality, and bank failure.

Consideration should be given to limit reservoir drawdown to less than 2 feet per day if embankment stability is in question. This drawdown guidance should only be used if practical and reasonable to do so.

Appendix B-2
Cherry Creek Water Control Plan

7-01. General Objectives. Engineering Regulation 1110-2-1400, dated 24 April 1970, assigns Corps of Engineers (Corps) reservoir regulation responsibilities in the Missouri River basin to the Missouri River Division Engineer, now the Northwestern Division Missouri River Basin Water Management (MRBWM) office. This engineering regulation permits delegation of certain reservoir regulation responsibilities to the District Engineer, in whose area the project is located. The responsibilities for assembly and interpretation of data affecting current reservoir regulation and for carrying out routine regulation of Cherry Creek Reservoir, according to plans agreed on in advance, have been delegated to the Omaha District Engineer. The Division Engineer, through the MRBWM office, monitors and reviews the regulation activities performed by the Omaha District. Plate 9-1 shows the organizational chart for the Omaha District in regards to Cherry Creek Reservoir regulation. Exhibit II contract between the United States of America and the State of Colorado, describes the operation of Cherry Creek for different pool elevations and reservoir zones.

The flood control storage of Cherry Creek Reservoir will be regulated primarily to prevent damage through the city of Denver from floods originating on Cherry Creek upstream of the project location. Secondary purposes include, when feasible, the minimizing of flood damages along the South Platte River in Denver and in downstream agricultural areas.

Fish and wildlife was not initially included as a project purpose; however, an objective was added to store and release basin flows to facilitate the management of fish and wildlife. Other objectives are to maintain and manage the land and water resources to support a diversity of fish and wildlife and to preserve, protect, and interpret threatened and endangered species and unique and important ecological resources.

7-02. Constraints. The control point for Cherry Creek Dam regulation is 5,000 cfs at the South Platte River at Denver stream gage. It is important to note that the 5,000 cfs flow includes Bear Creek and Chatfield Dam releases as well as incremental runoff downstream of each of the dams. Flood control operation is described in detail in section 7-05. Channel capacity varies widely downstream of the dam. Downstream inundation mapping for a reservoir release of 5,000 cfs from Cherry Creek Dam to the confluence with the South Platte River was finalized in March 2013 and depicts areas of out-of-bank flow. The sustained non-damaging channel capacity of Cherry Creek is likely between 4,000 and 5,000 cfs. Downstream channel concerns, gate vibration, manpower to make gate changes, and travel time for releases to impact downstream areas are items that may constrain operations.

Normally, increases in releases should not exceed 500 cfs per day. Release reduction rates should consider downstream impacts. Preferably, releases should be reduced at a similar rate of 500 cfs per day. However, if a higher rate of change is necessary to accommodate operational circumstances, releases may be increased or reduced at an accelerated rate. The release may even be reduced to flow in a single gate change if

required. Examples of downstream impacts include environmental, water quality, and bank failure. There should be communication with stakeholders if these rates of change will be exceeded.

a. Coordination with State Water Laws. At the request of the Governor, the Chief of Engineers has permitted the State of Colorado to maintain a conservation pool in the Cherry Creek Reservoir. Management of the conservation pool for recreational use, administration of water rights, and determination of reservoir evaporation are accomplished by the Division of Parks and Recreation in cooperation with the Colorado State Engineer. Extensive coordination is required between the Corps and the State while the pool level is within the conservation zone. It is essential that regulation be in accordance with the water requirements and irrigation laws of the State of Colorado, while also safeguarding the State's right to maintain storage in the conservation pool. Releases of small inflows, which cause pool rises slightly in excess of the conservation zone, are closely coordinated with the State Engineer. As such storage would have little or no effect in subsequent flood operations, releases generally can be made at slow rates more useful to irrigation interests. The release rates recommended by the State Engineer will normally be followed in such instances if no conflict with the flood control function would result.

b. Problems to be Encountered in Regulating Reservoir. Several factors exist that must be considered in regulation of the project:

(1) The Cherry Creek Project was authorized primarily to provide flood control through Denver from floods originating on Cherry Creek. Project releases must be carefully coordinated with incremental inflows to Cherry Creek below the dam so that project releases, when combined with the natural inflows, do not exceed the capacity of the Cherry Creek channel through Denver. Consideration must also be given to the combination of Cherry Creek flows with flows on the South Platte River through Denver to provide as much flood control on the South Platte River as possible consistent with the primary function of providing flood control along Cherry Creek through Denver.

(2) In regulating the reservoir, the restrictive capacity of the Cherry Creek channel through Denver, and especially through the area upstream of downtown Denver, may affect the maximum release that can be made from the project. The lined portion of the channel has deteriorated from lack of maintenance and infrequent use over the past several years. Willow growth and small rock dams in the unlined portion also pose a restriction to higher releases. The State Engineer has frequently indicated a preference for maximum releases of 2500 cfs insofar as practical. A steady release of 525 cfs was made for approximately twelve days during mid-August 1965 with no adverse effect. Although hydraulic studies indicate a probable channel carrying capacity of near 5000 cfs, any releases in excess of 1000 cfs must be carefully observed in the field. Annual sediment flushing releases of up to 1300 cfs have been made without problems, although these releases were of only a15-minute duration.

Project releases should be kept as high as practical based on field observations, but not exceeding 5000 cfs while the reservoir is below the spillway crest.

(3) Existence of the conservation pool presents several problems in regulation of the reservoir. The outlet gates are normally kept closed to retain the conservation pool. The project will not directly pass all inflows through the reservoir, including those flows less than 5000 cfs considered in the 1946 agreement as usable by downstream irrigation interests. The State Engineer is responsible for dealing with any water rights administration. When the reservoir is above the top of conservation zone releases will be determined by the Corps based on the primary requirements for flood control, reference Section 7-05 for details. Due consideration to the recommendations of the State Engineer will determine how much of the conservation storage will be evacuated following any inflow event.

(4) Subsequent to completion of the Cherry Creek Project, extensive commercial and residential development has occurred in the Sand Creek and Tollgate Creek flood plain downstream of the Cherry Creek spillway. Channel capacities have been restricted by encroachment and major damage will occur in the event of spillway use. If high inflows require use of the spillway, maximum utilization of the Cherry Creek channel through Denver should be considered to reduce the amount of discharge throughout the spillway and the associated damages along Sand and Tollgate Creeks.

(5) Extensive residential development has occurred on the properties adjacent to project boundaries, sometimes below the maximum pool elevation. This could cause problems trying to regulate the system of reservoirs (Cherry Creek, Bear Creek, and Chatfield). Public safety in these areas could also become a concern, due to the rapid rise of pool levels during storms of the design magnitude.

(6) During the flood of June 1965 an extensive amount of debris entered the reservoir and collected along the embankment near the intake tower. Since the flood inflow volume was rather small it was held in the reservoir until the debris could be removed. Releasing water while debris surrounds the tower could result in debris lodging in the gate slots and prevent closure of gates, with a resultant loss of all conservation storage. It is conceivable that larger gate openings or higher pool levels would remove the threat of obstruction in the gate passageway. Considerable dead timber is now lying in the reservoir above the conservation pool level and along the channel in the upper reaches of the basin. Careful attention should be given to the debris problem in future regulation of the reservoir.

(7) Cherry Creek, Bear Creek, and Chatfield Dam outflows require close coordination. Problems arise in maintaining appropriate storage balances considering storm recurrence and reservoir conditions within each project. Water rights and water ownership of temporarily impounded water require close coordination with the State Engineer's office.

(8) Revised PMF and design storm routings indicate inadequate flood control storage volume at the project. A Dam Safety Modification Study addressing this concern was initiated in FY 2013 and is scheduled to be completed in FY 2016. The study will develop and evaluate potential alternatives to reduce risks associated with Cherry Creek Dam. Regulation of the project will require close monitoring of Cherry Creek Reservoir and basin conditions.

7-03. Overall Plan for Water Control. The normal regulation of Cherry Creek Reservoir involves responsibilities of the State of Colorado and of the Corps. Refer to Exhibit II for more information.

The Definite Project Report, dated January 1944, did not present a detailed plan of conservation regulation for Cherry Creek Reservoir because no provision had been made for conservation storage in the reservoir. Following the retention of surplus runoff during the spring of 1957, a conservation pool was established in the reservoir at the request of the State Engineer. With the approval granting the State of Colorado authority to maintain a conservation pool in Cherry Creek Reservoir, the operating plan for flood control was revised to include plans for both conservation and flood control. The following paragraphs discuss in detail the current plan for regulation of the conservation storage. Section 7-05 describes flood control operation in detail. Pool storage zones and elevations are shown in a schematic on Plate 7-1.

a. State of Colorado Responsibilities - The regulation plan for the conservation zone (5504 - 5550.0 feet) is to store all inflows in excess of downstream water requirements. Requirements for the retention or release of storage while the reservoir is below elevation 5550.0 feet will be determined by the Colorado State Engineer consistent with water laws of Colorado. Normally the State Engineer will make requests for release of water directly to the Omaha District Water Control and Water Quality Section. Upon notification and concurrence with such proposed releases, the Water Control and Water Quality Section will issue a regulation order to the Tri-Lakes Project Office specifying the amount and duration of releases to be made. If an actual emergency exists involving drowning, present or probable damage to the public works downstream from the dam, or events of a similar nature, the State Engineer may issue release instructions to the Tri-Lakes Project Office for immediate action. The Tri-Lakes Project Office will confirm such action with the Water Control and Water Quality Section as soon as possible.

(1) Regulation Process. When it is the responsibility of the State of Colorado as indicated in section 7-03-a, the Colorado State Engineer will contact the Omaha District, Water Control and Water Quality Section for a regulation change due to downstream water rights. The State Engineer determines the necessary release with approval from the Water Control and Water Quality Section. The Water Control and Water Quality Section then contacts the Tri-Lakes Project Office with the regulation

change. The two Corps offices discuss the regulation change, and as long as there are no constraints the change is performed. An official reservoir regulation order will be issued in writing by the Water Control and Water Quality Section. Tri-Lakes Project Office personnel will record the gate setting for each gate change in the pool report spreadsheet which can be accessed by the Water Control Manager to complete the written order reservoir regulation order. A copy of all orders issued by the Water Control and Water Quality Section will be furnished to the State Engineer and the Tri-Lakes Project Office. Under normal circumstances, this copy will contain a brief statement giving the background and reasons for issuance of the order.

b. Corps of Engineers Responsibilities - The operation of Cherry Creek Reservoir involves two units of the Corps Omaha District as described in sections 7-03-b-1 and 7-03-b-2 below. Plate 9-1 shows the organizational chart for the Omaha District in regards to Cherry Creek Reservoir regulation. Additional responsibilities of the Corps are also outlined below.

(1) Water Control and Water Quality Section, Engineering Division. The Omaha District, Water Control and Water Quality Section is responsible for matters pertaining to the regulation of the reservoir. This office prepares the official forecasts for the Corps. Throughout the year the Water Control and Water Quality Section monitors reservoir releases made from the conservation pool by the State Engineer. When the pool level is in or forecasted by this office to enter the exclusive flood control pool, this office is responsible for scheduling reservoir releases to attain optimum flood control benefits and control of project storage to assure regulation in conformance with the authorized functions of the project. The Water Control and Water Quality Section is responsible for procurement of necessary snow pack, precipitation, streamflow, and reservoir elevation data, while also making advanced estimates of streamflow from snow cover and/or rainfall reports for regulation purposes and to alert field operating personnel of potential flood occurrences. The Water Control and Water Quality Section prepares the monthly reservoir report (MRD Form 0168) for Cherry Creek Reservoir, which contains the official daily elevation, inflow, and outflow, see Plate 9-2. Issuance of reservoir regulation orders as outlined in section 7-03-b-4 is also performed by the Water Control and Water Quality Section.

In the interest of regulation of the Cherry Creek Reservoir to serve the functions of (1) maintenance of the conservation pool, (2) control of flood flows on Cherry Creek, and (3) sediment flushing operations, while at the same time yielding incidental benefits to downstream irrigation interests and providing operational flexibility, it is desirable to maintain a small transition storage zone of approximately one foot between elevations 5550.0 and 5551.0 feet. In regulation of the conservation storage pool, the State Engineer will endeavor to keep the reservoir at or above elevation 5550.0 feet as inflows will permit. Numerous occasions arise when small Cherry Creek inflows or rainfall on the immediate reservoir area cause small increases in the pool level, many of which will cause the pool to exceed elevation 5550.0 feet. The release of these small

volumes will cause frequent and difficult gate operation. The quantity of water so released would also be insufficient in most instances to be practical or beneficial to State water users. If the State Engineer has no call for releases, these small inflows will be accumulated in the reservoir to a maximum elevation of 5551.0 feet. Upon reaching elevation 5551.0 feet, the Water Control and Water Quality Section will issue a regulation order to the Tri-Lakes Project Office to release this accumulated storage at a rate agreed upon between the Water Control and Water Quality Section and the State Engineer. The releases will be continued until the pool has receded to elevation 5550.0 feet. However, while the reservoir is between elevations 5550.0 and 5551.0 feet, the reservoir level may fluctuate as necessary without requiring frequent small reservoir releases. The schedule of releases will be coordinated between the State Engineer's Office and the Water Control and Water Quality Section.

(2) Tri-Lakes Project Office, Operations Division. The Operations Division plans and directs the maintenance and physical operation of the project. This Division establishes the standards of maintenance and provides proper staffing of operating personnel at the Tri-Lakes Project Office to accomplish these objectives. The Tri-Lakes Project Office staff performs all gate changes at Cherry Creek Dam. This office organized an informal agreement with the Colorado State Engineer that one gate change per week be made for downstream water rights. This was in response to no longer staffing a full-time dam tender on site at Cherry Creek Dam. This office has also agreed to initiate email or telephone correspondence for reservoir releases in excess of 40 cfs with the Urban Drainage and Flood Control District, a local agency that coordinates releases with local county emergency managers.

(3) Flood Period Organization. The normal organization of the Omaha District is somewhat modified during a flood period to take care of the additional duties made necessary by the flood emergency. These duties are to: 1) operate the flood control reservoirs for maximum protection; 2) collect and disseminate flood information; 3) protect Corps of Engineers' property and works; 4) obtain engineering data; and 5) in extreme emergency, assist in relief and rescue work. These activities take precedence over normal work and are performed by those employees of the District who have been trained for specific emergency duties. In case of purely local flooding in a reservoir controlled basin, such as Cherry Creek or Chatfield, only those units of the District Organization concerned with the normal operation of the reservoir are placed in an emergency status. A directory of regulation personnel is shown in the Standing Instructions to the Dam Tender, Exhibit I.

(4) Regulation Orders. Whether it is the responsibility of the State Engineer or the Omaha District Water Control and Water Quality Section, the Water Control and Water Quality Section will issue all regulation orders to the Tri-Lakes Project Office. All regulation orders will normally be issued verbally and then confirmed in writing as official signed orders as soon as possible. An official reservoir regulation order will be issued in writing by the Water Control and Water Quality Section for all

gate changes made at Cherry Creek Dam. Tri-Lakes Project Office personnel will record the gate setting for each gate change in the pool report spreadsheet, which can be accessed by the Water Control Manager to complete the written order. A copy of all orders issued by the Water Control and Water Quality Section will be furnished to the State Engineer and the Tri-Lakes Project Office. Under normal circumstances, this copy will contain a brief statement giving the background and reasons for issuance of the order. In the case of a dam safety issue or major flood control release, the signed reservoir regulation order should contain sufficient details to describe the reasoning of the reservoir regulation decision. In the case of a deviation from the water control plan, the reservoir regulation order should note that a signed deviation approval from the MRBWM office has been acquired.

(5) Emergency Organization. It is not anticipated that any emergency organization other than described in section 7-03-b-3, as described above, will be required. However, under the provisions of the Standing Instructions to the Dam Tender, reference section 7-04, communication failure during a flood event may result and isolate the dam tender, thus making that person the sole project operating organization.

(6) Coordination with Other Agencies. Daily project operating data and miscellaneous hydrologic information will be exchanged between the Project Office, the State Engineer and the Water Control and Water Quality Section. Cooperation is also maintained with the U.S. Geological Survey and Colorado Division of Water Resources relative to the collection and reporting of precipitation amounts, stream stages, and discharge. The Natural Resources Conservation Service provides snow pack and runoff forecasts, and the National Weather Service provides precipitation and stream gage forecasts.

(7) Communication. Telephone and email facilities are presently available for communication between the Project Office, State Engineer, and Water Control and Water Quality Section. In event of loss of these means of communication, the dam tender may communicate via vehicular travel between the respective offices noted above and/or via cellular phone.

7-04. Standing Instructions to Dam Tender. Exhibit I contains the Standing Instructions to Dam Tender. The Standing Instructions to the Dam Tender provides detailed instructions for regulation of project releases and storage under emergency conditions, such as communication failure. This failure may result and isolate the dam tender, thus making that person the sole project operating organization. Regulation orders issued verbally will be confirmed in writing as official signed orders as soon as possible.

7-05. Flood Control. Cherry Creek Dam and Reservoir will be regulated for flood control to mitigate risk to the metropolitan area of Denver from floods originating on

Cherry Creek upstream of the project location. Operation of the Cherry Creek Project will require both individual and system reservoir regulation.

a. Operation of Cherry Creek Reservoir as an Individual Project. Before 1985, the developed method of flood control regulation of Cherry Creek Reservoir was Method A defined in EM 1110-2-3600. This method is based on the concept of reducing downstream damaging stages as much as possible during each flood with the currently available storage space. After 1985, the method of flood control regulation became Method C. Method C is a combination of Methods A and B. Method B is regulation based on control of the project design flood. Method C allows some flexibility during certain times of the year, such as when pool levels are low, and then fixes the schedule of releases as the pool reaches certain critical levels. This change has been made to help improve the safe passage of major flood events that could cause emergency spillway discharges into the Tollgate Creek basin. It is imperative that the pool be drawn down to at least the half of the flood control zone prior to the occurrence of the spillway design flood. A release rate to a maximum of 5000 cfs from the Cherry Creek outlet works will ensure that no floodwaters are stored in the upper half of the flood control zone for more than 5 days. This will allow the project to contain a standard project flood on top of a half-full starting pool without diverting water into the adjacent Tollgate Creek basin. Evacuation of flood control storage from Cherry Creek Reservoir as an individual project will only occur when no flood storage is occupied in Bear Creek or Chatfield Reservoirs.

(1) Release Rates During Flood Inflows. When the reservoir is in the range of elevation 5551.0 to 5610.6 feet (spillway crest, surveyed in April 2008) and rising as a direct result of stream runoff, consideration will be given to utilizing release rates shown on Plate 7-2. This regulation schedule, or rule curve, was developed from procedures outlined in Chapter 4 of EM1110-2-3600 and illustrate the minimum release rates necessary to control the indicated inflow within the remaining flood control storage capacity of the reservoir. While the minimum release rates on Plate 7-2 are intended primarily as guidelines, actual release rates will be kept as large as feasible up to the maximum 5000 cfs target at the South Platte River at Denver, Colorado streamgage while minimizing flood risk on Cherry Creek and on the South Platte River below Cherry Creek. When the reservoir elevation reaches a half full flood pool, the reservoir release will be kept as large as feasible to meet the 5000 cfs target at the South Platte River at Denver, Colorado streamgage to decrease the risk of spillway flows.

(2) Outlet Works Release Rates During Flood Evacuation. When the reservoir inflow has peaked and the reservoir level becomes stationary or begins to fall, releases will be scheduled, consistent with downstream conditions, to evacuate the accumulated flood storage as rapidly as practical. In view of the severe shortage of water for irrigation along the South Platte River, it is also in the best interest of the government, when practical, to release stored flood waters at a rate beneficial to irrigation interests if such release rates will not unduly interfere with the primary flood

control function of the project. The release rates indicated on Plates 7-2 and 7-3 represent the minimum rate of release required to evacuate the reservoir in a practical period of time. The release rates on Plates 7-2 and 7-3 are based on an evacuation time of 8 days for the April-July period and a time of 10 days for the September-February period for pool levels above elevation 5572.0 feet. The evacuation time was lengthened to a maximum of 15 days for progressively lower pool levels. These evacuation times were selected as that which will reasonably allow for sufficient storage withdrawal in advance of subsequent flood reoccurrences. Consideration will be given to utilizing the evacuation rates shown on Plates 7-2 and 7-3 although higher rates will be utilized whenever feasible. While Plates 7-2 and 7-3 list flood control as the primary objective, some incidental conservation benefits will also be realized, particularly in evacuation of small or medium size floods.

(3) Spillway Releases. When the reservoir rises above the spillway crest elevation 5610.6 feet, releases will occur through the ungated spillway channel into West Tollgate Creek, and then into Tollgate Creek and Sand Creek, thus bypassing the Cherry Creek basin through the city of Denver as depicted in Plate 4-32. Since completion of the Cherry Creek Project, considerable residential and commercial development has taken place in the Tollgate and Sand Creek flood plains. Large spillway releases could result in considerable damage. The Corps has neither fee title nor flowage easements to lands along the channels. In order to decrease the possibility of spillway discharges, evacuation of the flood pool should be scheduled as soon as downstream conditions permit.

b. System Operating Plan for Flood Control Evacuation. System or coordinated regulation of Cherry Creek, Chatfield, and Bear Creek will be necessary only after flood flows have entered the reservoirs and during flood storage evacuation. When water has accumulated in the flood control storage zone of these projects, an equal protective balance of flood control storage kept vacant should be maintained during pool evacuation. This balance is based on establishing an equal risk in each project of filling the remaining flood control space from a similar subsequent flood. The storage remaining should provide equal protection at each project against runoff from rainfall of standard project flood magnitude. Flood storage evacuation will continue at Cherry Creek Dam until the pool elevation falls to 5550 feet, at which time coordination will resume with the State Engineer.

Two storage levels are established in each project. Generally, the upper Level II of storage space approximates the volume of the rainfall standard project flood. In Chatfield, Level II amounts to 160,000 acre-feet (af), the volume of the rainfall standard project flood. As the entire flood control space in both Cherry Creek and Bear Creek Reservoirs was designed mainly for protection from the sudden occurrence of a rainfall standard project flood and not from the longer duration mountain snowmelt flood, 95 percent of this space was assigned to Level II. The remaining five percent of flood storage in Cherry Creek and Bear Creek Reservoirs is allotted a lower evacuation rate

at the downstream control point, the South Platte River at Denver stream gage. This space was assigned to Level I to provide for a transition from flood releases to conservation releases and to lessen unnecessary slugging of high releases for small encroachments of the flood pools. The lower evacuation rate of this five percent of storage will not significantly affect the project flood control function. However, since individual design criteria for both the Chatfield and Cherry Creek Projects were based on releasing 5,000 cfs out of each project and not a target of 5,000 cfs at the South Platte River at Denver stream gage, which includes incremental runoff and releases from Chatfield, Cherry Creek and Bear Creek following the flood peak, strict adherence to these evacuation criteria should be followed. Tables 7-1 and 7-2 present a tabulation of storage in the three projects assigned to each level and desired evacuation flow to be targeted at the control point, South Platte River at Denver stream gage, depending on storage level, percent of storage space filled, and time of year. This system procedure is also presented in the Water Control Manuals for Chatfield Dam and Reservoir and Bear Creek Dam and Reservoir.

Table 7-1 lists the storage and elevations based on the following surveys: Cherry Creek (2007), Chatfield (2010), and Bear Creek (2009).

Table 7-1
FLOOD REGULATION STORAGE LEVELS

	Level I			Level II		
	Elevation (feet)	Storage (AF)	Incr. Storage (AF)	Elevation (feet)	Storage (AF)	Incr. Storage (AF)
Cherry Creek	5550.0	12,600		5554.4	16,500	
	to 5554.4	16,500	3,900*	to 5598.0	91,900	75,400
Chatfield***	5444.0	47,700		5455.3	73,100	
	to 5455.3	73,100	25,400**	to 5500.0	233,100	160,000
Bear Creek	5558.0	1,800		5569.2	3,300	
	to 5569.2	3,300	1,500*	to 5635.5	30,300	27,000

* 5 percent of total flood pool
** Total Flood Control Storage (233,100 af) minus 47,700 af = 185,400 af; 185,400 af minus Standard Project Rainfall Flood (160,000 af) = 25,400 af

*** Flood Control pool in 1973 Chatfield Preliminary Reservoir Regulation Manual indicates the base of the flood control pool at elevation 5430.0 feet. The base of the flood control pool was changed to 5432.0 feet in March 1979. The base of the exclusive flood control pool was changed to 5444.0 feet in 2013 in response to the reallocation of flood control storage to joint-use flood control and water supply.

Note: Based on area/capacity surveys from 2007 for Cherry Creek, 2010 for Chatfield, and 2009 for Bear Creek.

Table 7-2
DESIRED CONTROLLED FLOW TARGET - DENVER STREAM GAGING STATION

April – July:

Any Reservoir at Level II - 5000 cfs
All Reservoirs at Level I, with one or more, more than 50% filled - 5000 cfs
All Reservoirs at Level I, and all less than 50% filled - 4000 cfs

August - March:

Any Reservoir at Level II - 5000 cfs
All Reservoirs at Level I, with one or more, more than 50% filled - 4000 cfs
All Reservoirs at Level I, and all less than 50% filled - 3000 cfs

Water will be released from the reservoir with the highest percent of storage in the highest level occupied until the storage balance or the percent of storage filled, for the same level, is the same in all reservoirs. Plate 7-4 displays the parallel reservoir balance for the three projects in percent of storage space filled for the two levels. When all three reservoirs have the same percentage of storage in the same level, equal balance has been achieved. For example, all reservoirs are in balance at 50% full in Level II at the following storage levels: Chatfield, 153,000 af; Cherry Creek, 54,000 af; Bear Creek, 16,800 af. Table 7-3 was developed to determine when this condition of equal balance has been achieved. Table 7-3 gives the parallel reservoir balance for the three projects in percent of storage space filled for the two levels based on the amount in the incremental storage column for each level as shown in Table 7-1. When all reservoirs have the same remaining balance of storage, the storage should be kept in balance or the percent of storage filled should be kept the same until all water is evacuated. Table 7-3 shows percent of storage depletion required out of each reservoir to enable continued parallel reservoir balance for all combinations of the three projects that may contain storage. For example, a total of 100 af of flood control storage occupied among the Tri-Lakes projects would reflect an equal balance for Level I - Balance Combination C when Bear Creek had no flood control storage, Chatfield had 87 af (87%) of storage, and Cherry Creek had 13 af (13%) of storage.

TABLE 7-3
UPPER SOUTH PLATTE RESERVOIR SYSTEM
PERCENTAGE OF STORAGE DEPLETION REQUIRED OUT OF EACH RESERVOIR TO ENABLE A CONTINUED PARALLEL RESERVOIR BALANCE
(Values are in percent)

LEVEL II (see Table 7-1 for Elevations)			
Balance Combination	Chatfield	Bear Creek	Cherry Creek
A	61	10	29
B	86	14	0
C	68	0	32
D	0	26	74
LEVEL I (see Table 7-1 for Elevations)			
Balance Combination	Chatfield	Bear Creek	Cherry Creek
A	82	5	13
B	94	6	0
C	87	0	13
D	0	28	72

Following is an example illustrating how an equal parallel reservoir balance is maintained during storage evacuation using Table 7-3. This example assumes (1) all three reservoirs are in an equal balanced condition as indicated by balance combination A of Level II of Table 7-3, (2) a control point flow of 5000 cfs is targeted at the Denver gage, and (3) there are no downstream channel constraints below the three projects. Values tabulated are average daily flows in cfs. After the total release on line 3 is determined, the estimated inflow into the three projects is totaled (line 4). The difference between this total (inflow) and line 3 (release needed from 3 projects) represents the total storage depletion from the 3 projects. Table 7-3 is then utilized to determine what percent of this storage is required out of each reservoir to enable a continued parallel reservoir balance. The difference between the estimated inflow and storage depletion for each project represents the required release from that project. The total release from the 3 projects represents the required total release needed to target the desired flow at the South Platte River at Denver stream gage, including an allowance for incremental flow. A release of 1 cfs over a 24 hour period is equivalent to 2 af of storage.

1. Desired flow at South Platte River at Denver Stream Gage							5,000
2. Incremental flow* between 3 projects and Denver Gage**							500
3. Total release needed from 3 projects							**4500**
		Chatfield		Bear Creek		Cherry Creek	Total
4. Estimated inflow**		1,100		0		100	1,200
5. Storage depletion***	(61%)	2,000	(10%)	300	(29%)	1,000	3,300
6. Required release		3,100		300		1,100	**4,500**

* Incremental flows are flows that enter the stream downstream of dam releases
** Values to be estimated
*** Values from Table 7-3

7-06. Recreation. The demand for water-based recreation near the large metropolitan city of Denver is substantial. The Cherry Creek Project satisfies part of the demand. The multi-purpose pool, elevation 5504 to 5550 feet, is operated for multiple purposes, which include recreation, flood control, and fish and wildlife. The lands at the three Tri-Lakes projects are not used for hunting due to the urban character of the area. In order to initially fill the multi-purpose pool, local interests agreed to allow storing of water for the pool, recognizing the eventual depletion effects of the multi-purpose pool.

The Corps will continue to maintain a closely coordinated planning effort with the State of Colorado, Department of Natural Resources, and Colorado State Parks. The Corps constructed recreational areas upstream from the dam that the State of Colorado leases, operates, and maintains for recreation use. Visitation to the Cherry Creek Project grew from 1,233,000 in 1976 to approximately 5,850,000 visits per year in FY01 through FY10.

7-07. Water Quality. Although the Corps does not have specific responsibilities

related to water quality at Cherry Creek Reservoir, all management activities will be executed to protect and enhance the quality of water resources. Refer to section 4-08 for water quality information.

The Cherry Creek Basin Water Quality Authority (CCBWQA) maintains an on-going program that involves water quality monitoring.

7-08. Fish and Wildlife. Fish and wildlife is an authorized project purpose at the Cherry Creek Project.

The basic premise of the flood control aspect of the water control plan is to release stored waters in the flood control zone of the reservoir as soon as possible following inflow from a flood event. This premise may be consistent with management of the fish and wildlife resources of the project as it reduces to a minimum the possible impacts to aquatic and terrestrial wildlife and its habitat.

Certain species of fish, such as the northern pike, require flooded grassy shoreline for successful spawning. This must also occur during a certain period in the early spring and lake levels must be slowly rising. For Cherry Creek Reservoir, such a scenario would be unlikely because the typical spring runoff occurs later in the year and would possibly cause a sudden, rather than a gradual, rise.

Cherry Creek Reservoir is mostly a warm-water fishery because it is a relatively shallow, plains reservoir. Normal operations and normal springtime floodwater inflows would have little effect on the fishery from a water temperature standpoint. Flood inflows could, however, have a very negative impact, at least temporarily, on the lake fishery if the inflows were high in suspended solids by making the water turbid. High turbidity has the effect of reducing light levels in the lower depths of the lake and of interfering with oxygen transfer (breathing) in the aquatic life forms in the lake. As temporary storage increases water residence time, suspended solids will tend to settle out. Settling of particulates may result in the surface waters becoming less turbid, but degradation of organic matter associated with settling particles may deplete oxygen in deeper waters while burial of bottom dwelling organisms may increase sediment oxygen demand.

The outlet works have only a single level for releases. Thus it is not possible to mix water from multiple levels to manage for a particular species of fish.

Cherry Creek Reservoir is not a primary waterfowl habitat area. It is not on a major migration flyway and it lacks the vegetation and cover necessary for it to be an important stopover point during spring or fall migration. Some local nesting of a few common waterfowl species likely occurs at the project. Larger numbers of Canada Geese use the reservoir as a roosting area in the fall and winter. Normal flood control

operations would not be expected to have any significant impacts on such waterfowl nesting.

The U.S. Fish and Wildlife Service (F&WS) has responsibility for oversight of the Endangered Species Act. The F&WS maintains that temporary storage of floodwaters in upstream reservoirs may have impacts on species that depend on the Platte River downstream for part of their life requisites. The federal agencies that are responsible for manipulations of the Platte River system upstream are said to have some responsibilities for protection of those downstream species. The problem is complex; the major elements to it follow:

a. Detention of upstream floodwaters in upstream reservoirs reduces the peak and the overall volume of the effects the flood would otherwise have on downstream areas. The Platte River in Nebraska, for instance, no longer is impacted by heavy and prolonged spring flooding that once periodically scoured the channel and kept trees from gaining a foothold. Where the channel was once wide, shallow, and relatively treeless, it is now narrower, deeper, and heavily tree-covered in many areas. Each upstream reservoir adds to the situation in a cumulative manner.

b. The main species of concern on the central Platte River in Nebraska are the whooping crane, least tern, pallid sturgeon, and piping plover. All of these species have been designated as federally threatened or endangered. Upstream impoundments and increased depletions from the Platte River have adversely influenced habitat for these downstream species because they have changed the timing and volume of flows. These adverse impacts have accumulated over the past 40 years or more, and continue to influence the flood plain environment.

7-09. Water Supply. There is no water supply storage at the project at the present time.

7-10. Hydroelectric Power. None at this project.

7-11. Navigation. None at this project.

7-12. Drought Contingency Plans. No plan has been developed at this time. Guidance concerning the development of drought contingency plans is being reviewed and updated. A drought contingency plan for Cherry Creek Dam and Reservoir will be coordinated with stakeholders following the approval of the updated guidance.

7-13. Flood Emergency Action Plans. A procedure has been developed to determine project operations under emergency conditions so that the Tri-Lakes Project Office staff has appropriate information and instructions for modifying their existing regulation orders. This procedure is given under the Emergency Regulation part of the Standing Instructions to the Dam Tender (See Exhibit I). The procedure is defined to

begin with a failure of communications between the Tri-Lakes Project Office and the Omaha District Water Control and Water Quality Section personnel at a time when the reservoir is rising rapidly, high inflows are indicated, excessive rainfall has occurred, flooding below the dam is occurring or appears imminent, or when a combination of any of these is occurring. During such emergencies, regulation of project releases will be made by the Tri-Lakes Project Office in accordance with the release schedule given in Exhibit I. Continuing effort will be made to re-establish communications. The dam will be attended at all times during an emergency.

7-14. Deviation from Normal Regulation. Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. For example: (1) releases according to the schedule should not exceed downstream channel capacity unless the safety of the dam is in question; or (2) temporary delays of a few days duration in evacuation of flood storage will be considered to mitigate damages and/or for special circumstances downstream. Deviations require prior approval from the Northwestern Division Commander except as noted in section 7-14-a. Requests to deviate from normal regulation of the project fall into one of the categories described below.

a. Emergencies. Deviations from the release schedule will be made if emergency conditions exist upstream or downstream of the dam. Examples of these types of emergencies include dam safety emergencies, downstream chemical spills, drownings, and facility failures. During an emergency activity, the Omaha District will inform the MRBWM office of such activities as soon as possible. Written confirmation of the deviation, including a description of the cause of the emergency, will be furnished as soon as practicable to the MRBWM office as shown in NWDR 1110-2-6.

b. Unplanned Minor Deviations. Temporary delays of a few days duration in evacuation of flood storage will be considered to mitigate damages and/or for special circumstances downstream. A typical example of activities that would create the potential for unplanned minor deviations would be modifications of bridge and utility crossings. In evaluating requests for these types of deviations, the Omaha District will consider upstream watershed conditions, potential flood threats, the amount of water in storage in Cherry Creek Reservoir, and whether any alternative measures could be taken that would not require a deviation. Written request of the deviation and a description of the cause will be furnished to the MRBWM office as shown in NWDR 1110-2-6.

c. Planned Deviations. Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. All conditions such as data on flood potential, lake and watershed conditions, possible alternative measures, benefits to be expected, and probable effects on other authorized and useful purposes will be analyzed. Planned deviations will be coordinated with all appropriate entities, including locals and state offices, and a written request will be

furnished to the MRBWM office as shown in NWD 1110-2-6.

7-15. Rate of Release Change. Normally, increases in releases should not exceed 500 cfs per day. Release reduction rates should consider downstream impacts. Preferably, releases should be reduced at a similar rate of 500 cfs per day. However, if a higher rate of change is necessary to accommodate operational circumstances, releases may be increased or reduced at an accelerated rate. The release may even be reduced to zero flow in a single gate change if required. Examples of downstream impacts include environmental, water quality, and bank failure.

Consideration should be given to limit reservoir drawdown to less than 2 feet per day if embankment stability is in question. This drawdown guidance should only be used if practical and reasonable to do so.

Appendix B-3
Bear Creek Water Control Plan

7-01. General Objectives. Engineering Regulation 1110-2-1400, dated 24 April 1970, assigns Corps of Engineers (Corps) reservoir regulation responsibilities in the Missouri River basin to the Missouri River Division Engineer, now the Northwestern Division Missouri River Basin Water Management (MRBWM) office. This engineering regulation permits delegation of certain reservoir regulation responsibilities to the District Engineer, in whose area the project is located. The responsibilities for assembly and interpretation of data affecting current reservoir regulation and for carrying out routine regulation of Bear Creek Reservoir, according to plans agreed on in advance, have been delegated to the Omaha District Engineer. The Division Engineer, through the MRBWM office, monitors and reviews the regulation activities performed by the Omaha District. Plate 9-1 shows the organizational chart for the Omaha District in regards to Bear Creek Reservoir regulation. Exhibit II, a contract between the United States of America and the State of Colorado dated March 1988, describes the operation of Bear Creek for different pool elevations and reservoir zones.

Bear Creek Dam will be regulated for flood control primarily to prevent damage to the metropolitan area of Denver from floods originating on Bear Creek upstream of the dam and will also be regulated to provide for general recreation and fish and wildlife recreation purposes. Project regulation for these purposes is described in the following sections.

7-02. Constraints. The control point for Bear Creek Dam regulation is 5,000 cfs at the South Platte River at Denver stream gage. It is important to note that the 5,000 cfs flow includes Cherry Creek and Chatfield Dam releases as well as incremental runoff downstream of each of the dams. Flood control operation is described in detail in section 7-05. Channel capacity varies widely downstream of the dam. Downstream channel concerns, gate vibration, manpower to make gate changes, and travel time for releases to impact downstream areas are items that may constrain operations.

Normally, increases in releases should not exceed 200 to 300 cfs per day. Release reduction rates should consider downstream impacts. Preferably, releases should be reduced at a similar rate of 200 to 300 cfs per day. However, if a higher rate of change is necessary to accommodate operational circumstances, releases may be increased or reduced at an accelerated rate. The release may even be reduced to zero flow in a single gate change if required. Examples of downstream impacts include environmental, water quality, and bank failure. There should be communication with stakeholders if these rates of change will be exceeded.

7-03. Overall Plan for Water Control. The normal regulation of Bear Creek Reservoir involves responsibilities of the State of Colorado and of the Corps. Refer to Exhibit II for more information.

Normal operations at Bear Creek Reservoir specify that outflows equal inflows. Since the top of the multi-purpose pool is also the crest of the ungated weir, no specific

regulation of the water levels is anticipated when the pool elevation is above the elevation of the weir. Regulation for conservation will normally be automatic in that incoming water will flow via gravity over the weir crest. However, when the pool elevation is below the elevation of the weir, low level releases may need to be made for water rights administration. Two low level gated outlets are provided to permit releases of water from the multi-purpose pool for reservoir drawdown if the need arises. Fine regulation of low flow releases will be completed by a gate-within-a-gate (1-foot square opening) on each of the two service gates in the gate structure.

a. State of Colorado Responsibilities - As requested by the State of Colorado, releases below the top of the multipurpose pool (elevation 5558.0 feet, msl) will be made to supply irrigation and/or water supply diversions and normal river flows insofar as water is available. When the reservoir is at or below elevation 5558.0 feet, msl, releases will be made as directed by the Colorado State Engineer to satisfy all downstream water rights. To satisfy these rights the State has specified that, insofar as practical, the reservoir must be regulated so that reservoir inflow equals outflow except during periods of flood operations. The State Engineer will issue release changes directly to the Tri-Lakes Project Office when the pool elevation is below the top of the multipurpose pool (5558 feet). Exhibit II, a contract between the United States of America and the State of Colorado, describes the operation of Bear Creek for different pool elevations and reservoir zones.

b. Corps of Engineers Responsibilities - The operation of Bear Creek Reservoir involves two units of the Corps Omaha District as described in sections 7-03-b-1 and 7-03-b-2 below. Plate 9-1 shows the organizational chart for the Omaha District in regards to Bear Creek Reservoir regulation. Additional responsibilities of the Corps are also outlined below.

(1) Water Control and Water Quality Section, Engineering Division. The Omaha District, Water Control and Water Quality Section is responsible for matters pertaining to the regulation of the reservoir. This office prepares the official forecasts for the Corps. Throughout the year the Water Control and Water Quality Section monitors reservoir releases made from the conservation pool by the State Engineer. When the pool level is in or forecasted by this office to enter the exclusive flood control pool, this office is responsible for scheduling reservoir releases to attain optimum flood control benefits and control of project storage to assure regulation in conformance with the authorized functions of the project. The Water Control and Water Quality Section is responsible for procurement of necessary snow pack, precipitation, streamflow, and reservoir elevation data, while also making advanced estimates of streamflow from snow cover and/or rainfall reports for regulation purposes and to alert field operating personnel of potential flood occurrences. The Water Control and Water Quality Section prepares the monthly reservoir report (MRD Form 0168) for Bear Creek Reservoir, which contains the official daily elevation, inflow, and outflow, see Plate 9-2. Issuance

of reservoir regulation orders as outlined in section 7-03-b-4 is also performed by the Water Control and Water Quality Section.

(2) Tri-Lakes Project Office, Operations Division. The Operations Division plans and directs the maintenance and physical operation of the project. This Division establishes the standards of maintenance and provides proper staffing of operating personnel at the Tri-Lakes Project Office to accomplish these objectives. The Tri-Lakes Project Office staff performs all gate changes at Bear Creek Dam. This office has agreed to initiate email or telephone correspondence for reservoir releases in excess of 500 cfs with the Urban Drainage and Flood Control District, a local agency that coordinates releases with local county emergency managers.

(3) Flood Period Organization. The normal organization of the Omaha District is somewhat modified during a flood period to take care of the additional duties made necessary by the flood emergency. These duties are to: 1) operate the flood control reservoirs for maximum protection; 2) collect and disseminate flood information; 3) protect Corps of Engineers' property and works; 4) obtain engineering data; and 5) in extreme emergency, assist in relief and rescue work. These activities take precedence over normal work and are performed by those employees of the District who have been trained for specific emergency duties. In case of purely local flooding in a reservoir controlled basin, such as Bear Creek or Chatfield, only those units of the District Organization concerned with the normal operation of the reservoir are placed in an emergency status. A directory of regulation personnel is shown in the Standing Instructions to the Dam Tender, Exhibit I.

(4) Regulation Orders. When it is the responsibility of their respective offices as indicated in section 7-03-a and -b, the State Engineer and the Omaha District Water Control and Water Quality Section will issue regulation orders directly to the Tri-Lakes Project Office. All requests for regulation of project releases, other than regulation responsibilities of the State Engineer, will be referred to the Water Control and Water Quality Section for approval and issuance of orders. All regulation orders will normally be issued verbally and then confirmed in writing as official signed orders as soon as possible. An official reservoir regulation order will be issued in writing by the Water Control and Water Quality Section for all gate changes made at Bear Creek Dam, those initiated by the State Engineer and otherwise. Tri-Lakes Project Office personnel will record the gate setting for each gate change in the pool report spreadsheet, which can be accessed by the Water Control Manager to complete the written order. A copy of all orders issued by the Water Control and Water Quality Section will be furnished to the State Engineer and the Tri-Lakes Project Office. Under normal circumstances, this copy will contain a brief statement giving the background and reasons for issuance of the order. In the case of a dam safety issue or major flood control release, the signed reservoir regulation order should contain sufficient details to describe the reasoning of the reservoir regulation decision. In the case of a deviation from the water control plan, the reservoir regulation order should note that a signed deviation approval from the

MRBWM office has been acquired.

(5) Emergency Organization. It is not anticipated that any emergency organization other than described in section 7-03-b-3 will be required. However, under the provisions of the Standing Instructions to the Dam Tender, reference section 7-04, communication failure during a flood event may result and isolate the dam tender, thus making that person the sole project operating organization.

(6) Coordination with Other Agencies. Daily project operating data and miscellaneous hydrologic information will be exchanged between the Project Office, the State Engineer and the Water Control and Water Quality Section. Cooperation is also maintained with the U.S. Geological Survey and Colorado Division of Water Resources relative to the collection and reporting of precipitation amounts, stream stages, and discharge. The Natural Resources Conservation Service provides snow pack and runoff forecasts, and the National Weather Service provides precipitation and stream gage forecasts.

(7) Communication. Telephone and email facilities are presently available for communication between the Project Office, State Engineer, and Water Control and Water Quality Section. In event of loss of these means of communication, the dam tender may communicate via vehicular travel between the respective offices noted above and/or via cellular phone.

7-04. Standing Instructions to Dam Tender. Exhibit I contains the Standing Instructions to Dam Tender. The Standing Instructions to the Dam Tender provides detailed instructions for regulation of project releases and storage under emergency conditions, such as communication failure. This failure may result and isolate the dam tender, thus making that person the sole project operating organization. Regulation orders issued verbally will be confirmed in writing as official signed orders as soon as possible.

7-05. Flood Control. Bear Creek Dam and Reservoir will be regulated for flood control to mitigate risk to the metropolitan area of Denver from floods originating on Bear Creek upstream of the project location. Operation of the Bear Creek Project will require both individual and system reservoir regulation.

a. Operation of Bear Creek Reservoir as an Individual Project. In general, the developed method of flood control regulation of Bear Creek Reservoir may be classified as Method C, defined in EM 1110-2-3600. This represents a combination of the concept of reducing downstream damaging stages as much as possible during each flood with the currently available storage space, with consideration of control of floods of project design magnitude. Evacuation of flood control storage from Bear Creek Reservoir as an individual project will only occur when no flood storage is occupied in Cherry Creek or Chatfield Reservoirs.

During flood or apparent flood situations, Bear Creek releases will be reduced to as low as zero in an effort to reduce downstream flooding or essential downstream water right requirements as determined by the State. The standard project rainfall flood design routing assumed no release for two days. The 300-year, 60-day inflow volume design routing assumed releases as given by the reservoir release schedule in Table 7-1. However, due to short peaking times, this may not be possible in all instances. Following cessation of downstream flooding and stabilization of stream flows, releases will be made in accordance with the release schedule outlined in Table 7-1.

Table 7-1
BEAR CREEK RESERVOIR RELEASE SCHEDULE

Reservoir Elevation Feet, msl		Release Rate (cfs)
From	To	
5558.0	5611.5	Streamflow up to 500
5611.5	5625.0	1000
5625.0	5635.5	1500
5635.5	5667.0	2000

Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. For example, 1) releases according to the schedule should not exceed downstream channel capacity unless the safety of the dam is in question and 2) temporary delays of a few days duration in evacuation of flood storage will be considered so the water can be utilized by downstream users.

Evacuation of flood storage should be made as soon as practical after the flood event. Releases should be made at the highest practical rate to permit rapid drawdown of the flood pool for control of subsequent flood events. In view of the severe shortage of water for irrigation along the South Platte River, it is also in the best interest of the government, when practical, to release stored flood waters at a rate beneficial to irrigation interests if such release rates will not unduly interfere with the primary flood control function of the project.

In determination of the spillway design routing, no water was released through the gated outlet works. However, in event of actual surcharge and spillway operation, release of water through the gated outlet must be considered. The release schedule specifies a release of 2000 cfs in the portion of the surcharge zone between the top of the flood zone (elevation 5535.5 feet, msl) and the spillway crest (elevation 5567.0 feet, msl). The gated outlets should also be utilized to provide a gradual transition of project

releases from gated surcharge operation (pool level just below spillway crest) and spillway surcharge operation (pool level above spillway crest).

b. System Operating Plan for Flood Control Evacuation. System or coordinated regulation of Cherry Creek, Chatfield, and Bear Creek Reservoirs will be necessary only after flood flows have entered the reservoirs and during flood storage evacuation. When water has accumulated in the flood control storage zone of these projects, an equal protective balance of flood control storage kept vacant should be maintained during pool evacuation. This balance is based on establishing an equal risk in each project of filling the remaining flood control space from a similar subsequent flood. The storage remaining should provide equal protection at each project against runoff from rainfall of standard project flood magnitude. Flood storage evacuation will continue at Bear Creek Dam until the pool elevation falls to 5558 feet, at which time coordination will resume with the State Engineer.

Two storage levels are established in each project. Generally, the upper Level II of storage space approximates the volume of the rainfall standard project flood. In Chatfield, Level II amounts to 160,000 acre-feet (af), the volume of the rainfall standard project flood. As the entire flood control space in both Cherry Creek and Bear Creek Reservoirs was designed mainly for protection from the sudden occurrence of a rainfall standard project flood and not from the longer duration mountain snowmelt flood, 95 percent of this space was assigned to Level II. The remaining five percent of flood storage in Cherry Creek and Bear Creek Reservoirs is allotted a lower evacuation rate at the downstream control point, the South Platte River at Denver stream gage. This space was assigned to Level I to provide for a transition from flood releases to conservation releases and to lessen unnecessary slugging of high releases for small encroachments of the flood pools. The lower evacuation rate of this five percent of storage will not significantly affect the project flood control function. However, since individual design criteria for both the Chatfield and Cherry Creek Projects were based on releasing 5,000 cfs out of each project and not a target of 5,000 cfs at the South Platte River at Denver stream gage, which includes incremental runoff and releases from Chatfield, Cherry Creek, and Bear Creek following the flood peak, strict adherence to these evacuation criteria should be followed. Tables 7-2 and 7-3 present a tabulation of storage in the three projects assigned to each level and desired evacuation flow to be targeted at the control point, South Platte River at Denver stream gage, depending on storage level, percent of storage space filled, and time of year. This system procedure is also presented in the Water Control Manuals for Cherry Creek Dam and Reservoir and Chatfield Dam and Reservoir.

Table 7-2 lists the storage and elevations based on the following surveys: Cherry Creek (2007), Chatfield (2010), and Bear Creek (2009).

Table 7-2
FLOOD REGULATION STORAGE LEVELS

	Level I			Level II		
	Elevation (feet)	Storage (AF)	Incr. Storage (AF)	Elevation (feet)	Storage (AF)	Incr. Storage (AF)
Cherry Creek	5550.0	12,600		5554.4	16,500	
	to 5554.4	16,500	3,900*	to 5598.0	91,900	75,400
Chatfield***	5444.0	47,700		5455.3	73,100	
	to 5455.3	73,100	25,400**	to 5500.0	233,100	160,000
Bear Creek	5558.0	1,800		5569.2	3,300	
	to 5569.2	3,300	1,500*	to 5635.5	30,300	27,000

* 5 percent of total flood pool
** Total Flood Control Storage (233,100 af) minus 47,700 af = 185,400 af; 185,400 af minus Standard Project Rainfall Flood (160,000 af) = 25,400 af

*** Flood Control pool in 1973 Chatfield Preliminary Reservoir Regulation Manual indicates the base of the flood control pool at elevation 5430.0 feet. The base of the flood control pool was changed to 5432.0 feet in March 1979. The base of the exclusive flood control pool was changed to 5444.0 feet in 2013 in response to the reallocation of flood control storage to joint-use flood control and water supply.

Note: Based on area/capacity surveys from 2007 for Cherry Creek, 2010 for Chatfield, and 2009 for Bear Creek.

Table 7-3
DESIRED CONTROLLED FLOW TARGET - DENVER STREAM GAGING STATION

April – July:

Any Reservoir at Level II - 5000 cfs
All Reservoirs at Level I, with one or more, more than 50% filled - 5000 cfs
All Reservoirs at Level I, and all less than 50% filled - 4000 cfs

August - March:

Any Reservoir at Level II - 5000 cfs
All Reservoirs at Level I, with one or more, more than 50% filled - 4000 cfs
All Reservoirs at Level I, and all less than 50% filled - 3000 cfs

Water will be released from the reservoir with the highest percent of storage in the highest level occupied until the storage balance or the percent of storage filled, for the same level, is the same in all reservoirs. Plate 7-4 displays the parallel reservoir balance for the three projects in percent of storage space filled for the two levels. When all three reservoirs have the same percentage of storage in the same level, equal balance has been achieved. For example, all reservoirs are in balance at 50% full in

Level II at the following storage levels: Chatfield, 153,000 af; Cherry Creek, 54,000 af; Bear Creek, 16,800 af. Table 7-4 was developed to determine when this condition of equal balance has been achieved. Table 7-4 gives the parallel reservoir balance for the three projects in percent of storage space filled for the two levels based on the amount in the incremental storage column for each level as shown in Table 7-2. When all reservoirs have the same remaining balance of storage, the storage should be kept in balance or the percent of storage filled should be kept the same until all water is evacuated. Table 7-4 shows percent of storage depletion required out of each reservoir to enable continued parallel reservoir balance for all combinations of the three projects that may contain storage. For example, a total of 100 af of flood control storage occupied among the Tri-Lakes projects would reflect an equal balance for Level I - Balance Combination C when Bear Creek had no flood control storage, Chatfield had 87 af (87%) of storage, and Cherry Creek had 13 af (13%) of storage.

TABLE 7-4
UPPER SOUTH PLATTE RESERVOIR SYSTEM
PERCENTAGE OF STORAGE DEPLETION REQUIRED OUT OF EACH RESERVOIR TO ENABLE A CONTINUED PARALLEL RESERVOIR BALANCE
(Values are in percent)

LEVEL II (see Table 7-2 for Elevations)			
Balance Combination	Chatfield	Bear Creek	Cherry Creek
A	61	10	29
B	86	14	0
C	68	0	32
D	0	26	74
LEVEL I (see Table 7-2 for Elevations)			
Balance Combination	Chatfield	Bear Creek	Cherry Creek
A	82	5	13
B	94	6	0
C	87	0	13
D	0	28	72

Following is an example illustrating how an equal parallel reservoir balance is maintained during storage evacuation using Table 7-4. This example assumes (1) all three reservoirs are in an equal balanced condition as indicated by balance combination A of Level II of Table 7-4, (2) a control point flow of 5000 cfs is targeted at the Denver gage, and (3) there are no downstream channel constraints below the three projects. Values tabulated are average daily flows in cfs. After the total release on line 3 is determined, the estimated inflow into the three projects is totaled (line 4). The difference between this total (inflow) and line 3 (release needed from 3 projects) represents the total storage depletion from the 3 projects. Table 7-4 is then utilized to determine what percent of this storage is required out of each reservoir to enable a continued parallel reservoir balance. The difference between the estimated inflow and storage depletion for each project represents the required release from that project. The total release from the 3 projects represents the required total release needed to target the desired flow at the South Platte River at Denver stream gage, including an allowance for incremental flow. A release of 1 cfs over a 24 hour period is equivalent to 2 af of storage.

1. Desired flow at South Platte River at Denver Stream Gage							5,000
2. Incremental flow* between 3 projects and Denver Gage**							500
3. Total release needed from 3 projects							**4500**
		Chatfield		Bear Creek		Cherry Creek	Total
4. Estimated inflow**		1,100		0		100	1,200
5. Storage depletion***	(61%)	2,000	(10%)	300	(29%)	1,000	3,300
6. Required release		3,100		300		1,100	**4,500**

* Incremental flows are flows that enter the stream downstream of dam releases
** Values to be estimated
*** Values from Table 7-4

7-06. Recreation. The demand for water-based recreation near the large metropolitan city of Denver is substantial. The Bear Creek Project satisfies part of the demand. The multi-purpose pool, elevation 5528 to 5558 feet, is operated for multiple purposes, which include recreation, flood control, and fish and wildlife. The majority of water surface recreation areas in the Bear Creek Reservoir zone of influence are either too small to accommodate boating activity or are used as water supply reservoirs in which body contact recreation and boating activities are prohibited. Bear Creek Reservoir is large enough for boating and provides an excellent fishery. The lands at the three Tri-Lakes projects are not used for hunting due to the urban character of the area. In order to initially fill the multi-purpose pool, local interests agreed to allow storing of water for the pool, recognizing the eventual depletion effects of the multi-purpose pool. Exhibit III is a copy of the letter from the State Division of Game, Fish, and Parks indicating the State's obligation to furnish water for recreation in the Bear Creek multi-purpose pool. The State must provide sufficient water to fill the reservoir to the multi-purpose pool elevation of 5558.0 feet, msl and to replace annual evaporation losses.

The Corps will continue to maintain a closely coordinated planning effort with the State of Colorado, Department of Natural Resources, and Colorado State Parks. The Corps constructed recreational areas upstream from the dam that the State of Colorado leases, operates, and maintains for recreation use. Visitation to the Bear Creek Project grew from 30,800 in 1982 to approximately 1,495,000 visits per year in FY01 through FY10.

7-07. Water Quality. When Bear Creek Reservoir is in the flood control zone water quality is not a factor in the function of this project (reference Bear Creek Design Memorandum No. PB-9 Outlet Works, paragraph 4.3.2.5). Also, refer to section 4-08 for water quality information.

The Bear Creek Watershed Association maintains an on-going program that involves water quality monitoring and management of some upstream activities such as sewage treatment.

7-08. Fish and Wildlife. Fish and wildlife is an authorized project purpose at the Bear Creek Project.

Normal operations at Bear Creek Lake specify that outflows equal inflows. The basic premise of the flood control aspect of the water control plan is to release stored waters in the flood control zone of the reservoir as soon as possible following inflow from a flood event. This is consistent with optimum management of the fish and wildlife resources of the project as it reduces to a minimum the possible impacts to terrestrial wildlife and its habitat.

Bear Creek Reservoir is a cold water fishery because it is located near the Hogback Ridge of the Rocky Mountains and is fed by two mountain streams. The outlet works have only a single level for releases. Thus, it is not possible to mix water from multiple levels to manage for a particular species of fish. Normal operations and normal springtime flood water inflows have little effect on the fishery from a water temperature standpoint. Flood inflows could, however, have a negative impact, at least temporarily, on the lake fishery and even on the creeks at the upstream limits of the lake if the inflows were high in suspended solids, thus making the water turbid. High turbidity has the effect of reducing light levels in the lower depths of the lake and of interfering with oxygen transfer (breathing) in the aquatic life forms in the lake. As temporary storage increases water residence time, suspended solids will tend to settle out. Settling of particulates may result in the surface waters becoming less turbid, but degradation of organic matter associated with settling particles may deplete oxygen in deeper waters while burial of bottom dwelling organisms may increase sediment oxygen demand.

Bear Creek Reservoir is not a primary waterfowl habitat area. It is not on a major migration flyway and it lacks the vegetation and cover necessary for it to be an important stopover point during spring or fall migration. Some local nesting of a few

common waterfowl species likely occurs at the project. Larger numbers of Canada Geese use the reservoir as a roosting area in the fall and winter. Normal flood control operations would not be expected to have any significant impacts on such waterfowl nesting.

The U.S. Fish and Wildlife Service (F&WS) has responsibility for oversight of the Endangered Species Act. The F&WS maintains that temporary storage of floodwaters in upstream reservoirs may have impacts on species that depend on the Platte River downstream for part of their life requisites. The federal agencies that are responsible for manipulations of the Platte River system upstream are said to have some responsibilities for protection of those downstream species. The problem is complex; the major elements to it follow:

a. Detention of upstream floodwaters in upstream reservoirs reduces the peak and the overall volume of the effects the flood would otherwise have on downstream areas. The Platte River in Nebraska, for instance, no longer is impacted by heavy and prolonged spring flooding that once periodically scoured the channel and kept trees from gaining a foothold. Where the channel was once wide, shallow, and relatively treeless, it is now narrower, deeper, and heavily tree-covered in many areas. Each upstream reservoir adds to the situation in a cumulative manner.

b. The main species of concern on the central Platte River in Nebraska are the whooping crane, least tern, pallid sturgeon, and piping plover. All of these species have been designated as federally threatened or endangered. Upstream impoundments and increased depletions from the Platte River have adversely influenced habitat for these downstream species because they have changed the timing and volume of flows. These adverse impacts have accumulated over the past 40 years or more, and continue to influence the flood plain environment.

7-09. Water Supply. The semiarid climate east of the Rocky Mountains, with its low annual precipitation and the rapid growth in population, has made water a jealously guarded element of life in Colorado. The continued growth of the need for water for domestic, irrigation, and industrial uses will tend to assure the further development of water supplies for use in the South Platte River basin. The strategic location of the Tri-Lakes Project reservoirs near the city of Denver and their capacity make them an important factor for inclusion in any water program. Irrigation and water rights play an important part in use and regulation of flows of streams within the State of Colorado. Water rights are jealously guarded and the State of Colorado has requested regulation of the Cherry Creek, Bear Creek, and Chatfield Projects to protect these interests.

Bear Creek provides a valuable source of water supply for the South Platte River basin. It is estimated that 11 percent of the average annual runoff at the Denver gaging station on the South Platte River is from Bear Creek. Bear Creek's contribution would be more except that much of its water is utilized within the basin. As is typical of the South Platte

River basin, water resources of the Bear Creek basin are over appropriated. Stream runoff appropriations are administered by the Colorado State Engineer under a priority system of water rights. Under this system, appropriations with senior water rights have prior claim to stream flows, and junior water rights are satisfied only when stream flow is sufficient to first fulfill priority rights. The aggregate of existing water rights on the water resources of the Bear Creek basin exceeds the normal range of runoff experience.

Since construction of Bear Creek Dam, the Omaha District entered into two temporary one-year storage contracts for municipal and industrial water supply under Section 6 of the Flood Control Act of 1944 (Public Law 34, 78th Congress), pending development of a long-term contract under the Water Supply Act of 1958 as amended (43 U.S.C. 390 b-f). The first contract dated September 17, 1987 was for 25 af with the Indian Hills Water District. This contract has been renewed each year.

Most of the water rights diversions from Bear Creek were originally intended for agricultural purposes and the decrees were for irrigation or agricultural uses. With urbanization in the basin, there has been a gradual change from agricultural to other uses, such as domestic, industrial, and irrigation of golf course areas and lawns. Table 7-5 lists the average monthly stream flow loss or gain and the maximum monthly loss between the Morrison and Sheridan stream gaging stations.

Table 7-5
BEAR CREEK AVERAGE MONTHLY WATER DEPLETION IN CFS
Between Morrison and Sheridan Stream Gaging Stations
(1928 - 1974 Period)

Month	Gain or Loss	Maximum Loss - Year	
January	+ 6.5	- 4	1945
February	+ 5.2	- 20	1936
March	+ 0.6	- 16	1936
April	+ 2.3	- 25	1938
May	+12.1	- 133	1936
June	- 38.0	- 130	1936
July	- 47.4	- 127	1949
August	- 37.4	- 104	1930
September	- 29.7	- 115	1938
October	- 7.9	- 84	1939
November	0	- 13	1960
December	+ 5.0	- 6	1949

Five major ditches operate on Bear Creek between Morrison and Sheridan. Most of this water is diverted to storage facilities for municipal or agricultural use. These ditches and the approximate appropriation for each are listed in Table 7-6.

Table 7-6
Bear Creek Basin Ditches

DITCH	WATER RIGHT APPROPRIATION	LOCATION
Harriman	25 cfs	downstream edge of Morrison
Ward	5 cfs	Bear Creek Reservoir Tail Race
Hodson	2 cfs	south side of Kipling Street
Pioneer Union	2.5 cfs	Bear Creek Reservoir Tail Race
McBroom	1 cfs	1/8 mile upstream of Sheridan gage

7-10. Hydroelectric Power. None at this project.

7-11. Navigation. None at this project.

7-12. Drought Contingency Plans. No plan has been developed at this time. Guidance concerning the development of drought contingency plans is being reviewed and updated. A drought contingency plan for Bear Creek Dam and Reservoir will be coordinated with stakeholders following the approval of the updated guidance.

7-13. Flood Emergency Action Plans. A procedure has been developed to determine project operations under emergency conditions so that the Tri-Lakes Project Office staff has appropriate information and instructions for modifying their existing regulation orders. This procedure is given under the Emergency Regulation part of the Standing Instructions to the Dam Tender (See Exhibit I). The procedure is defined to begin with a failure of communications between the Tri-Lakes Project Office and the Omaha District Water Control and Water Quality Section personnel at a time when the reservoir is rising rapidly, high inflows are indicated, excessive rainfall has occurred, flooding below the dam is occurring or appears imminent, or when a combination of any of these is occurring. During such emergencies, regulation of project releases will be made by the Tri-Lakes Project Office in accordance with the release schedule given in Exhibit I. Continuing effort will be made to re-establish communications. The dam will be attended at all times during an emergency.

7-14. Deviation from Normal Regulation. Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. For example: (1) releases according to the schedule should not exceed downstream channel capacity unless the safety of the dam is in question; or (2) temporary delays of

a few days duration in evacuation of flood storage will be considered to mitigate damages and/or for special circumstances downstream. Deviations require prior approval from the Northwestern Division Commander except as noted in section 7-14-a. Requests to deviate from normal regulation of the project fall into one of the categories described below.

a. Emergencies. Deviations from the release schedule will be made if emergency conditions exist upstream or downstream of the dam. Examples of these types of emergencies include dam safety emergencies, downstream chemical spills, drownings, and facility failures. During an emergency activity, the Omaha District will inform the MRBWM office of its activities as soon as possible. Written confirmation of the deviation, including a description of the cause of the emergency, will be furnished as soon as practicable to the MRBWM office as shown in NWDR 1110-2-6.

b. Unplanned Minor Deviations. Temporary delays of a few days duration in evacuation of flood storage will be considered to mitigate damages and/or for special circumstances downstream. A typical example of activities that would create the potential for unplanned minor deviations would be modifications of bridge and utility crossings. In evaluating requests for these types of deviations, the Omaha District will consider upstream watershed conditions, potential flood threats, the amount of water in storage in Bear Creek Reservoir, and whether any alternative measures could be taken that would not require a deviation. Written request of the deviation and a description of the cause will be furnished to the MRBWM office as shown in NWDR 1110-2-6.

c. Planned Deviations. Deviations from the release schedule will be made if conditions at the time are such that improved reservoir regulation will result. All conditions such as data on flood potential, lake and watershed conditions, possible alternative measures, benefits to be expected, and probable effects on other authorized and useful purposes will be analyzed. Planned deviations will be coordinated with all appropriate entities, including locals and state offices, and a written request will be furnished to the MRBWM office as shown in NWD 1110-2-6.

7-15. Rate of Release Change. Bear Creek does not have any constraints (see release schedule in Section 7-05). However, based on past experience, increases in releases should be limited based on unforeseen downstream conditions, approximately 200 cfs to 300 cfs per day. Preferably, releases should be reduced at a similar rate. However, if a higher rate of change is necessary to accommodate operational circumstances, releases may be increased or reduced at an accelerated rate. The release may even be reduced to zero flow in a single gate change if required. Examples of downstream impacts include environmental, water quality, and bank failure.

When the reservoir is above elevation 5638.5 feet, msl consideration should be given to limiting reservoir decline to less than 2 feet per day, if possible, due to the steep

embankment along the dam face. Below the 5638.5 feet, msl elevation, rate of decline is not as critical due to the flatter slopes on the embankment. This drawdown guidance should only be used if practical and reasonable to do so.

Appendix C
Water Supply Demand Analysis

INTRODUCTION

This Appendix to the FR/EIS provides additional information on the "Water Demand Analysis" discussed in Chapter 1 and Chapter 2 of the FR/EIS. Portions of the Statewide Water Supply Initiative (SWSI) Phase I Report (Colorado Water Conservation Board 2004) that are relevant to the Chatfield Storage Reallocation project are included in this Appendix to the FR/EIS. The entire SWSI report is available online at http://cwcb.state.co.us/IWMD/Pubs.htm. Also included are selected portions of the South Metro Water Supply Study (Black & Veatch et al. 2003). The entire document is available online at http://www.crwcd.org/media/uploads/SouthMetroWaterSupplyStudy11-03.pdf. References and legal citations were omitted from this Appendix, but can be viewed on the original document.

STATEWIDE WATER SUPPLY INITIATIVE

SECTION 1—INTRODUCTION

1.1 Introduction to the Statewide Water Supply Initiative

In 2003, the Colorado legislature recognized the critical need to understand and better prepare for our long-term water needs, and authorized the Colorado Water Conservation Board (CWCB) to implement the Statewide Water Supply Initiative (SWSI). SWSI is a comprehensive study of how Colorado will meet its future water needs.

The overall objective of SWSI is to help Colorado maintain an adequate water supply for its citizens and the environment. SWSI is not intended to take the place of local water planning initiatives. Rather, it is a "forum" to develop a common understanding of existing water supplies and future water supply needs and demands throughout Colorado, and possible means of meeting those needs. CWCB, through SWSI and future efforts, will help support and/or identify solutions to these water supply needs. To help attain this goal, SWSI summarized by river basin, at a reconnaissance level, existing water supplies and demands and projected demands up to 30 years into the future, and a range of potential options to meet existing and future demands. This will allow water providers, state policy makers, and the General Assembly to make informed decisions regarding the management and use of Colorado's surface and groundwater resources.

In many areas, local planning entities have completed studies, identified projects, and are capable of implementing those projects. For areas where specific projects were not identified by water providers or water users, SWSI relied on a stakeholder process. The options developed by the SWSI stakeholder process generally fall within the following categories:

- Conservation
- Agricultural transfers
- Reservoir storage
- Conjunctive use of alluvial or non-tributary groundwater
- Water reuse
- Control of non-native phreatophytes (water consuming plants)

By taking both a basin and statewide perspective, SWSI has identified issues and water supply needs and projects that may require coordination by more than one planning entity, or that may be beyond the capabilities of a single entity. Through the SWSI effort, CWCB has identified possible solutions to achieve a cooperative and collaborative initiative.

1.2 Background on Colorado Water Resources

Eight major river basins drain Colorado, all with their headwaters in the high mountains of the Continental Divide. Rivers east of the Divide flow ultimately into the Gulf of Mexico, while the western rivers find their way, via the Colorado River, to the Gulf of California and the Pacific Ocean.

1.2.2 South Platte River

The South Platte River drains the most populous section of the state and serves the area with the greatest concentration of irrigated agricultural lands. Its waters originate chiefly in the mountain streams along the north half of the Front Range of the Eastern Slope. The main stream moves north, then east, and meets the North Platte in southwestern Nebraska. This basin comprises about 20 percent of the state's land area.

Water supply in the South Platte Basin is supplemented by transbasin diversions from the Colorado River Basin and to a lesser degree from the Arkansas River Basin. Here, new industry and rapidly expanding urbanized areas compete with agriculture for the same supplies of water.

While both rural and urban centers are growing, this growth does not represent agricultural growth since the trend is toward urbanization. Less than one-third of the land in this basin is public land.

1.2.5 Overview of Supplies

In Colorado, both surface and groundwater are used for irrigation and other agricultural uses, municipal and industrial (M&I) supplies, and domestic uses. On the Western Slope, although there is some domestic use of groundwater, the main source of supply is surface water. In the San Luis Valley, both surface and groundwater supplies are used, while on the eastern plains the primary source is groundwater for all uses. Front Range cities rely mostly on surface water (some of it diverted from the Western Slope), but many smaller towns and more rural subdivisions use groundwater. Agriculture and municipalities in the northeastern and southeastern parts of the state use large amounts of surface water including diversions from the Western Slope, but groundwater is also heavily used.

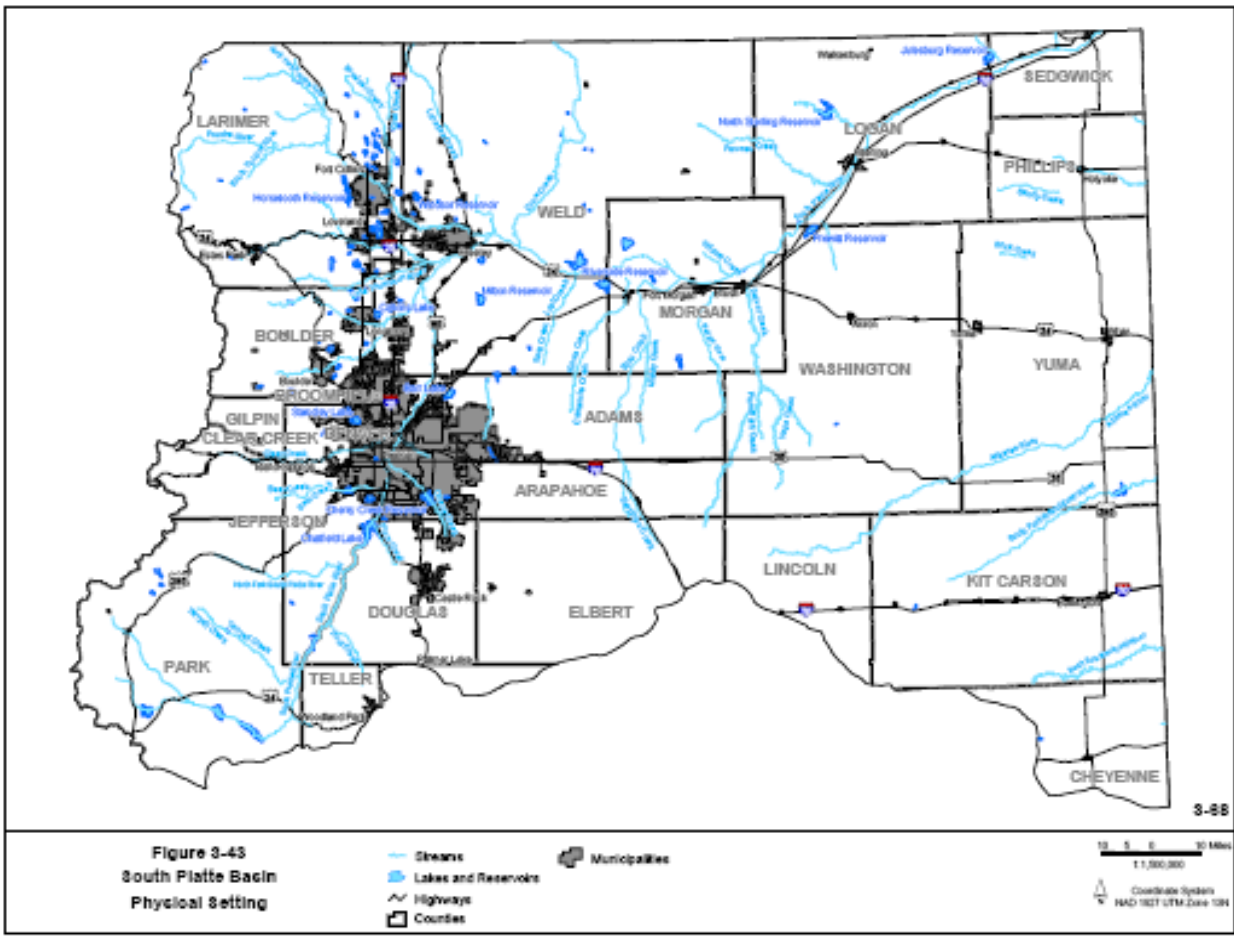
Surface water supplies depend on precipitation, much of which originates as snowpack in the state's high mountainous areas. The Continental Divide dictates the direction of water flow either to the west or to the east for each of the river systems in the state. Colorado is unique in that each of its major river systems originates in the state; water not captured or used in the state flows on to neighboring states and in many cases is governed by interstate compacts and agreements.

There are billions of gallons of groundwater in the confined (artesian) aquifers. Some major aquifers are the Ogallala in eastern Colorado; the Denver Basin, which stretches from Fort Collins to Colorado Springs; and another underlying the San Luis Valley.

SECTION 3—PHYSICAL ENVIRONMENT OF THE MAJOR RIVER BASINS

3.8.1 South Platte Basin Geography

The South Platte Basin (including the Republican River Basin) covers approximately 27,660 square miles in northeast Colorado, Figure 3-43. The largest cities in the basin are Denver (population 560,882), Aurora (population 287,216), and Lakewood (population 144,150).



3.8.2 South Platte Basin Climate

The South Platte Basin receives relatively low precipitation, which can be highly variable from year to year. The basin also has widely variable daily and seasonal air temperatures. The plains region is characterized by small amounts of precipitation averaging between 7 and 17 inches per year. Greater amounts of precipitation accumulate in the mountain region, which receive upwards of 30 inches annually. The foothills of the Front Range, which provide a transition zone between the mountains and the plains, annually receive an average of 17 to 21 inches of precipitation. The potential evapotranspiration exceeds precipitation in the basin in all areas except for the mountain region.

3.8.3 South Platte Basin Topography

The topographic characteristics of the South Platte Basin are diverse. Elevations in the basin range from over 14,000 feet at the headwaters near the Continental Divide to 3,400 feet at the Colorado/Nebraska state line. The headwaters of the South Platte River originate at an elevation of about 11,500 feet.

3.8.4 South Platte Basin Land Use

Approximately one-third of the basin's land area is publicly owned, and the majority of these lands are forest areas in the mountains. Western portions of the basin and its montane and subalpine areas are primarily forested, while the High Plains region is mainly grassland and planted/cultivated land.

3.8.5 South Platte Basin Surface Geology

The mountains are comprised of Precambrian age metamorphic and igneous basement rocks. These rocks come into contact with Mesozoic and Paleozoic sedimentary rocks by a fault that runs north and south just west of Denver. A well-known outcrop is observed along I-70 just west of C-470 revealing the many layers of sedimentary rock that form the Denver Basin.

3.8.6 South Platte Basin Surface Water

The South Platte River emerges out of the mountains southwest of the Denver metro region, flows through the Denver metropolitan urban area, and then enters the High Plains Region.

Major mountain tributaries to the South Platte River from upstream to downstream include the North, Middle, and South Forks of the South Platte River (upstream of Chatfield Reservoir), Bear Creek, Clear Creek, St. Vrain Creek, the Big Thompson River, and the Cache la Poudre River, as shown in Figure 3-43. Tributaries from the Plains region include Plum, Cherry, Sand Creek, Box Elder, Kiowa, Bijou, Badger, Beaver, and Wildcat Creeks. The tributaries as well as the South Platte River have highly variable streamflows, with snowmelt runoff and summer thunderstorms dictating the flow in the spring and summer. The USGS monitors these streamflows with various gages located throughout the basin.

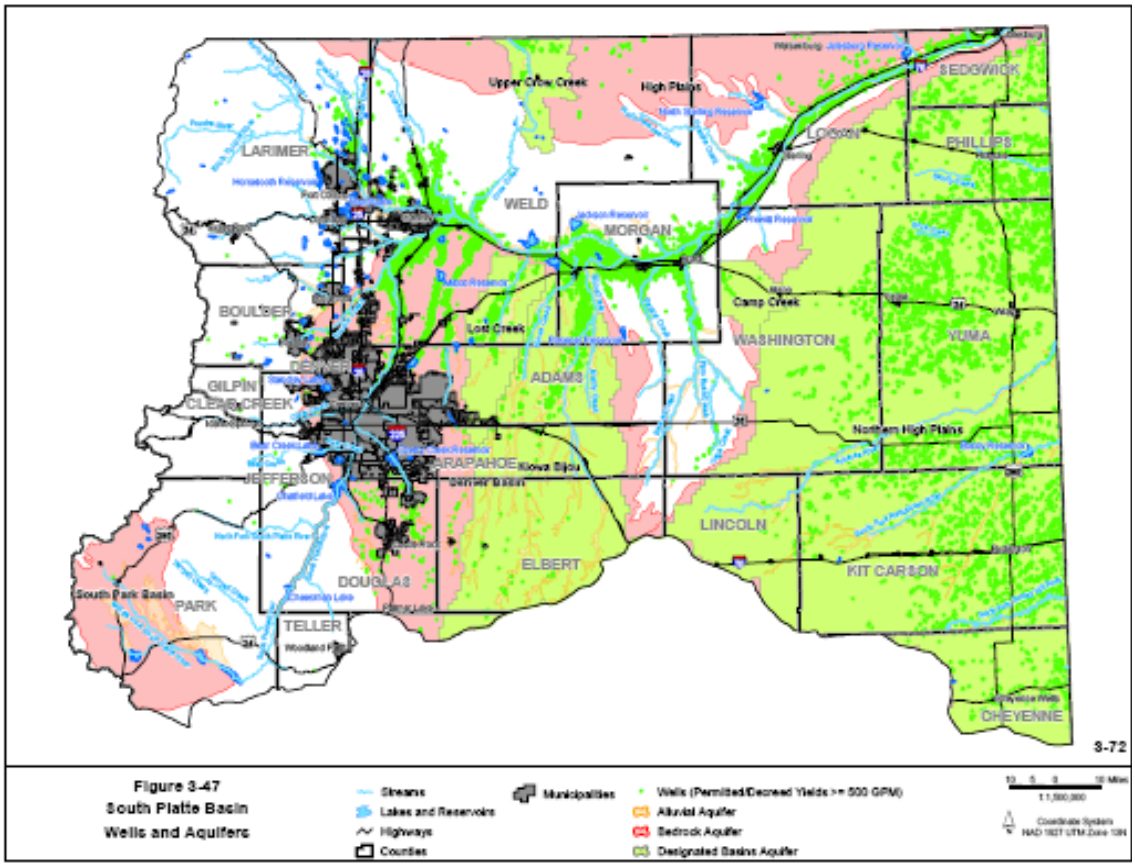
3.8.7 South Platte Basin Groundwater

Groundwater is a substantial resource in the South Platte Basin. Approximately 880,000 acre-feet per year (AFY) of groundwater in the South Platte Basin is used for irrigation, and 100,000 AFY is used to meet municipal, domestic, livestock, industrial, and commercial purposes. These values do not include groundwater pumped from the Ogallala Aquifer. Residents in Phillips, Yuma, Washington, Kit Carson, Cheyenne, Lincoln, and Elbert counties rely almost entirely on groundwater. Those living in the counties of Sedgwick, Morgan, Weld, Adams, and Douglas also use groundwater to meet a large portion of their water demand.

Figure 3-47 shows the location of the significant aquifers in the South Platte Basin and wells with permitted or decreed capacities greater than or equal to 500 gpm. These aquifers are as follows:

- Alluvial Aquifer
- Dawson
- Denver
- Arapahoe
- Laramie-Fox Hills
- Upper Cow Creek
- Camp Creek
- Northern High Plains
- Lost Creek
- Kiowa-Bijou

As shown in Figure 3-47, the bedrock aquifer is comprised of the Dawson, Denver, Arapahoe, and Laramie-Fox Hills. The designated groundwater basins include the Upper Crow Creek, Camp Creek, Northern High Plains, Lost Creek, and Kiowa-Bijou aquifers.



The reach of the South Platte River that begins southwest of the Denver Metro area and continues downstream to the state line is underlain by valley fill sediment forming the alluvial aquifer. This alluvial aquifer is composed primarily of poorly sorted gravel, sand, and clay. The saturated alluvium increases from 20 feet near Denver to over 200 feet at Julesburg with the thickest section running along the center of the historic river channel.

The alluvial aquifer is estimated to contain as much as 8.3 million AF in storage and is hydraulically connected to the river. Therefore, groundwater withdrawals, of which the majority are junior in priority to most surface water rights, can greatly affect the flow of the lower South Platte River. This segment, which is downstream of metro Denver, gives rise to the need for well augmentation plans to protect senior water rights.

In the lower South Platte River alluvium, there are approximately 10,880 permitted wells with yields ranging in capacity from 1 to 3,000 gpm. The average yield is 430 gpm; however, 50 percent of the wells have a yield of 30 gpm or less, which is biased by domestic wells.

The Denver Basin aquifers, which cover approximately 6,800 square miles, are comprised of the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers, are another important water resource for the South Platte Basin. The Denver Basin consists of Tertiary and Cretaceous age sedimentary rocks that supply groundwater for domestic, commercial, municipal, agricultural, and other users.

There are also five Designated Groundwater Basins in the South Platte Basin, which include the Upper Crow Creek, Camp Creek, Northern High Plains, Lost Creek, and Kiowa-Bijou. Designated groundwater is water that under natural conditions would not be used to recharge or supplement continuously flowing surface streams.

The Northern High Plains aquifer, which includes the Ogallala aquifer located in the Republican River Basin, is found in the eastern edge of Colorado in the High Plains region and is a major source of water for this agricultural region. Groundwater withdrawals have exceeded recharge since the early 1960s. The mean well yield from this aquifer is 373 gpm and the median is 20 gpm.

3.8.8 South Platte Basin Water Quality

There is a broad range of water quality in the South Platte Basin, ranging from high-quality mountain streams to those impacted due to urbanization and agricultural activities.

The upper South Platte River watershed is an area that has been affected by historic mining districts (i.e., Mosquito Creek), water resource development (i.e., South Park Dams and water diversions), and severe sediment deposition from forest fires such as the recent Hayman, Buffalo Creek and Hi Meadows fires.

The middle reach of the watershed, from below Chatfield Reservoir to the confluence with the Cache la Poudre River, has experienced some of the most intense use and resultant impacts of any river in Colorado. This segment of the river has seen historic mining districts, explosive urban development, stormwater runoff, extensive hydrologic modification, urban and agricultural nutrient loading, and effects of Superfund sites. Pollutants that have impaired the waters of the South Platte Basin include nitrate, ammonia, and copper. Furthermore, the South Platte River through and downstream of the Denver urban area exceeds E. coli standards.

The lower reach of the South Platte River, from the Cache la Poudre River to Julesburg, has been affected by upstream urbanization, historic agricultural land use, and waste disposal due to animal feeding operations. Non-point source pollution from pesticide and fertilizer runoff is the primary concern in this segment of the lower South Platte River.

Downstream of the Denver area, groundwater in the alluvial aquifer exceeds the nitrate limit for drinking water standards in some areas. The nitrate contamination not only affects the drinking water supply of several eastern plains cities, but can also be detrimental to certain crops when used for irrigation.

Groundwater in the alluvial aquifer near Denver contains approximately 1,000 ppm TDS. This concentration increases to about 4,000 ppm near Sterling. Surface water at the state line with Nebraska has an average TDS concentration of 1,300 ppm. These concentrations are of concern because water containing greater than 2,000 ppm TDS is generally considered to be unsuitable for irrigation.

Stream segments proposed for listing via the 2004 303(d) list and the accompanying Monitoring and Evaluation list are described in Colorado WQCC Regulations 93 and 94. The state's 2004 proposed 303(d) list incorporates several additions from the 2002 list. It includes numerous surface waters that span the basin's diverse topography and land uses. Listed segments proposed for the upper South

Platte and its tributaries, such as Clear Creek, are primarily listed for metals such as cadmium, copper, and zinc. Certain stream segments in urbanized areas are listed for bacteria and other constituents. A variety of constituents comprises the remainder of the listings for other parts of the basin, including several segments listed for selenium.

3.8.9 South Platte Basin Areas of Environmental Concern, Special Attention Areas, and Threatened and Endangered Species

As described above, various reaches of the South Platte River in the Denver Metro Area have water quality issues. High TDS and nitrate in the groundwater of the alluvial aquifer is also a concern.

Acid mine drainage, whirling disease, sedimentation, and wetland protection in the South Platte River headwaters have been problems as well. Wetlands are important in that they "have a well-documented capacity for extracting metals, particularly uranium, from ground and surface waters containing very dilute concentrations of the metals." A 1992 USGS study, Uranium and Other Elements in Colorado Rocky Mountain Wetlands – A Reconnaissance Study, sampled 145 montane and subalpine wetlands in Colorado to assess the concentration of uranium and other heavy metals in the wetlands. Forty-six percent of all the wetlands that were analyzed showed moderate or greater enrichment in uranium. If a wetland is partially or completed drained, oxidation of the organic-rich sediments might liberate the heavy metals that have accumulated in the wetlands over thousands of years. Therefore, the protection of wetlands, a natural water filter, is important to prevent environmental and health concerns.

In addition to impaired areas, threatened and endangered species and areas of high environmental or recreational value require special attention when evaluating water supply projects and water use in the South Platte Basin. For a complete list of federal and/or state listed threatened and endangered fish and other species in the South Platte Basin, along with information on RICDs in Fort Collins, Golden, and Longmont.

An example of an area with high-quality aquatic habitat in the South Platte Basin is the 3-mile section below Cheesman Dam that produces more than 500 pounds of fish per surface acre, mostly rainbow trout from 15 to 22 inches. Other areas that are valued for their fishing opportunities in the basin include the following Gold Medal designated segments:

- The South Fork downstream from the Highway 285 bridge to the inlet of Antero Reservoir
- The Middle Fork downstream from the Highway 9 Bridge (4.9 miles north of Garo) to the confluence of the Middle and South Forks and the South Platte River
- From the Middle and South Forks downstream through Spinney Mountain Reservoir to the buoy line at the inlet of Elevenmile Reservoir
- From Cheesman Reservoir Dam downstream to the North Fork of the South Platte River
- Spinney Mountain Reservoir, on the South Platte River about 5 miles upstream from Elevenmile Reservoir

Areas of high recreational value in the basin include Mount Evans Wilderness Area, Rocky Mountain National Park, and Chatfield State Park.

3.8.10 South Platte Basin Energy and Mineral Resources

More than 250 identifiable minerals have been located in deposits in the South Platte Basin. Other important natural resources in the basin include natural gas, petroleum, and coal. Over 130 million tons of coal was produced from the Denver Basin from 1883 to 1978.

SECTION 4—LEGAL FRAMEWORK FOR WATER USE

4.3 Specific Tools for Addressing Water Needs

There are a number of specific tools within the current legal framework of the Priority System (those with senior rights can require full or partial curtailment of diversions by junior water users) that can be used to address various water supply needs. These specific tools include the following.

4.3.1 Water Storage Rights

There are two different types of water rights – direct flow water rights and storage water rights. Direct flow rights allow a water user to divert water for immediate use, while storage rights allow a water user to divert water and store it to make a beneficial use at a later time. Storage rights, like other water rights, are assigned a priority and must be exercised without injury to other water rights. Storage rights are obviously a very important mechanism for ensuring that water supplies will be adequate in times of drought. Moreover, reservoirs provide year-round water when stream levels drop following the snow melt each year. Over the years, there have been numerous water storage projects undertaken by Colorado irrigation districts, water conservation districts, M&I water providers, and the federal government.

4.3.2 Conditional Water Rights

A conditional water right is defined in the 1969 Act as "a right to perfect a water right with a certain priority upon the completion with reasonable diligence of the appropriation upon which such water right is based." A conditional water right allows an appropriator to secure a place in the priority line before any water is actually applied to beneficial use. To obtain a conditional water right, the applicant must show that the "first step" towards the appropriation has been taken. The "first step" includes the intent to appropriate, plus a demonstration of that intent through "physical acts sufficient to constitute notice to third parties." Once the appropriator actually places the water to beneficial use, an absolute decree may be issued with a priority date relating back to the date the appropriation was initiated through the "first step."

As explained by the Colorado Supreme Court in Public Service Co. vs. Blue River Irrig. Co., a conditional water right "encourage[s] development of water resources by allowing the applicant to complete financing, engineering, and construction with the certainty that if its development plan succeeds, it will be able to obtain an absolute water right." Conditional water rights are crucial to large-scale development projects, including most transmountain diversions and storage projects, because they allow an appropriator to secure a priority and protect its investment when water cannot immediately be placed to beneficial use. Thus, conditional water rights are a tool that may be used to

complete major water projects, including storage reservoirs, transmountain diversion projects, or pipelines to meet water needs.

4.3.3 Changes of Water Rights

A change of water rights is another tool that allows water users flexibility to maximize the potential use of water. As described in the 1969 Act, a change of water rights includes "a change in the type, place, or time of use, a change in the point of diversion," and changes in the manner or place of storage. A change of water right will not be allowed unless it is approved by the water court, upon a finding that the change "will not injuriously affect the owner of, or persons entitled to use, water under a vested water right or a decreed conditional water right."

In a change case, the measure of the water right is the amount that was historically consumed (not the amount diverted) under the water right. Thus, only the amount of water that historically has not returned to the stream system under the original decreed use may be changed to a new place or type of use. This limitation ensures that the change will not enlarge the historical impact of the water right on the stream system, avoiding injury to other water users. In addition, in a change of water right proceeding, the applicant must take appropriate steps to ensure that historical return flows from the use of the water in amount, timing, and location are maintained. This is required because other water users rely, and are legally entitled to rely, on those return flows to support their appropriation and uses of water.

Changes of water rights allow for the reallocation of water resources to meet changing demands. For example, in Colorado, the largest water demand is for irrigated agriculture. With increasing urbanization, however, ever larger amounts of water are needed for municipal uses. To meet this demand, municipal entities can purchase senior agricultural water rights and change them to municipal uses. Likewise, the CWCB can also purchase agricultural water rights and change them to instream flow uses. All of these activities, however, must satisfy the "no injury" requirements in terms of maintaining historical return flows and preventing an expansion of historical CU.

Increasing the efficiency of use of a water right may not require a change of water right proceeding in all instances. For example, an agricultural user may change his method of irrigation (e.g., from flood to drip or sprinkler irrigation), yet still maintain the overall decreed use of irrigation. Although such activities may not require a change of use proceeding in water court, arguably this activity could have a detrimental impact on other water users to the extent that the change in irrigation alters return flows or the CU of a right.

Adjudicating a change of water rights can be time consuming and costly, and formal notification is required by law. Even when no parties object to the change, the process of water court approval takes a minimum of 3 months, and often much longer due to the heavy case load of water court judges. If parties do oppose a change case, it can take years to get a change decree approved by the court. In addition to paying attorneys' fees, an applicant for a change of water rights generally must hire an engineering consultant to prepare a report explaining the technical aspects of the change and develop an accounting form for administering the change. In order to avoid these costs and to speed the process, Colorado's legislature recently enacted legislation that authorizes a water right owner to lease water under the right without formal adjudication of change of water right. This legislation is discussed immediately below.

4.3.4 Leases of Water

During the 2003 legislative session, C.R.S. §§ 37-80.5- 101 to 105 were amended to authorize the State Engineer to create water banks within each water division, and to adopt rules governing their operation. The aim of this legislation is to simplify the process for temporary transfers of water rights by eliminating the adjudication proceedings required for a permanent change of water rights. The statute provides that the rules shall allow for the "lease, exchange, or loan of stored water within a water division," including a transfer to the CWCB for instream flow purposes, without the need to submit to any adjudication proceedings. Notwithstanding the fact that the lease, exchange, or loan is not adjudicated, such arrangements will still be subject to administration by the Division Engineer, within the priority system, to prevent material injury to other water users.

Another area of potential leasing involves agreements between agricultural and municipal/industrial users for interruptible supplies. Although this approach may require obtaining a change of use decree, it would potentially allow flexibility between agricultural and municipal/industrial users to rotate or fallow crops in certain years, thereby freeing up water supplies for municipal/industrial uses during such years. The terms of any such interruptible supply agreements would vary on a case-by-case basis, but could potentially allow for continued agricultural use in some, but not all, years. In order to be effective, such agreements need to be sufficiently long-term and reliable for municipal/industrial users to allow the sale of municipal taps on such basis. Moreover, any such arrangement would necessarily require protections to ensure that no expansion of use could occur to the detriment of junior water rights holders.

4.3.5 Augmentation Plans

An augmentation plan allows a water user to divert water out-of-priority from its decreed point of diversion, so long as replacement water is provided to the stream from another source, to make up for any deficit to other water users. An augmentation plan, like a change of water right, must be approved by the water court and is also subject to the "no injury rule." Accordingly, the 1969 Act requires substituted water to be "of a quality and quantity to meet the requirements for which the water of the senior appropriator has normally been used[.]"

As explained by the Colorado Supreme Court in re Application of Midway Ranches v. Midway Ranches Property Owners Association, Inc., "[a]ugmentation plans implement the Colorado doctrine of optimum use and priority administration, which favors management of Colorado's water resource to extend its benefit for multiple beneficial purposes." Augmentation plans provide a statutory mechanism for many different types of water users, big and small, to obtain water when and where they need it, by using other sources of water to replace or "augment" the out of priority depletions that result from their water use. In times of scarcity, an augmentation plan allows a water user to continue diverting even under a relatively junior priority, so long as it can provide replacement water to satisfy the needs of downstream seniors. As noted above, however, under an augmentation plan, a water user is essentially replacing the amount of water consumed with a different source of water. The water user gets credit for the amount of water it diverts that returns to the stream unconsumed. As a result, increased efficiency of use under an augmentation plan potentially reduces the amount of credit a water user receives for water returned to the stream unconsumed.

4.3.6 Instream Flows

Under the 1969 Act, the CWCB is authorized to appropriate water for "minimum stream flows or for natural surface water levels or volumes for natural lakes to preserve the natural environment to a reasonable degree." Appropriations for instream flows may only be made by the CWCB, not by private individuals (however, it is noted that a few private instream flows were obtained in the early 1970s upon initial passage of the statute, but this is no longer allowed under the law), and must be made within the priority system, consistent with the restrictions in Sections 5 and 6 of Colorado's Constitution. The CWCB can also acquire water rights for instream flows "by grant purchase, donation, bequest, devise, lease, exchange, or other contractual agreement."

In recent years, Colorado's legislature has expanded the resources available to the CWCB to protect instream flows. In 2002, the legislature increased the sources of funding that the CWCB may use to acquire water for instream flows, to include "any funds available to it, other than the construction fund created in section 37-60-121, for acquisition of water rights and their conversion to instream flow rights. In 2003, the legislature amended § 37-83-105, C.R.S., which provides for temporary loans or exchanges of water between water users in times of drought without requiring adjudication of a change of water rights, to allow the CWCB to receive loaned water for instream flow purposes on a temporary basis, not to exceed 120 days, in any basin where the Governor has declared a drought or other emergency. Such loans are subject to a determination by the State Engineer that other water users will not be injured.

It is essential that the state be able to acquire water rights for instream flow purposes in order to protect wildlife and the environment in a prior appropriation state during times of drought. Since Colorado water law does not allow the state to consider environmental factors in allocating or administering water, the only way for the state to ensure protection of stream flows for public purposes is by acquiring water rights, itself, within the priority system. By acquiring a water right with an enforceable priority, the state can place environmental concerns on equal footing with agricultural, commercial, municipal, and other uses of water. This means that in times of scarcity, the state's instream flows will be protected in a manner consistent with their priorities – to the extent the priorities are junior to other water rights, the CWCB's instream flows will be curtailed to make water available to other senior water users, and to the extent the CWCB's priorities are senior, the CWCB may request the Division Engineer to curtail more junior users to protect its instream flows.

In Colorado, recreation is a recognized beneficial use. Governmental entities can appropriate water solely for the purposes of recreation and boating. Recent enthusiasm for kayaking, and the appropriation of water for in-channel use, has sparked further debate among water users regarding this use of water.

For example, the City of Golden pursued an application for an in-channel water right for a kayak course. Golden sought to appropriate 1,000 cfs for this purpose, which essentially equates to all the water in Clear Creek during peak flow in most years. On appeal, the Supreme Court, from which one member recused himself, split equally, so that the water court's decree adjudicating this issue was affirmed.

In reaction to various claims for in-channel recreation rights, the General Assembly enacted legislation limiting the right to appropriate RICDs to municipal entities for "minimum streamflow as

it is diverted, captured, controlled, and placed to beneficial use between specific points defined by physical control structures for a reasonable recreation experience in and on the water." Applicants for such rights now must forward their application to the CWCB for review. After reviewing the application, the CWCB makes a recommendation to the water court on whether the application should be granted, granted with conditions, or denied.

4.3.7 New Appropriations

Making a new appropriation is always an option for water planning. Although some river basins are currently over-appropriated, in every basin there are usually a few days a year in which a free river condition exists and all rights can divert. Thus, while a 2004 priority is a very junior right, and will probably not have a reliable supply of water during the periods of high senior demands, it may still be possible to divert water under such a right at peak flow times. In addition, one could use an augmentation plan in conjunction with a very junior right to obtain a stable water supply.

To make an appropriation, one must have a specific intent to divert water for a beneficial use and perform a physical act in furtherance of that intent. Today, new appropriations are often made by filing an Application for a Water Right in the water court. However, no appropriation can be made when "the proposed appropriation is based on the speculative sale or transfer of the appropriative rights." This anti-speculation doctrine prevents individuals or entitles from acquiring water rights solely to sell to others. The waters of Colorado are a public resource and as such are not to be hoarded by those who do not have a present use for the water.

4.3.8 Groundwater Rights

In Colorado, there are four different types of groundwater:

- Tributary groundwater
- Non-tributary groundwater
- Not non-tributary groundwater
- Designated groundwater

The classification in which the groundwater falls determines how the water is allocated. Thus, while tributary groundwater is subject to the prior appropriation system, non-tributary groundwater and not non-tributary groundwater is allocated according to land ownership, and designated groundwater is subject to a modified prior appropriation system within each designated basin.

Tributary groundwater is water that is hydrologically connected to a surface stream. In Colorado, all groundwater is presumed to be tributary to a surface stream. In the early 1900s, Colorado courts held that tributary groundwater is subject to the prior appropriation system. The court based its decision, in part, on the fact that wells that intercept tributary groundwater actually deplete the stream flow to the detriment of senior surface appropriators.

Non-tributary groundwater is statutorily defined as that groundwater, outside the boundaries of a designated basin, "the withdrawal of which will not, within one hundred years, deplete the flow of a natural stream … at an annual rate greater than one-tenth of one percent of the annual rate of withdrawal." The right to use non-tributary groundwater is purely a function of statute. The General Assembly has recognized that non-tributary groundwater is a finite resource and has specifically

declared that "such water shall be allocated…upon the basis of ownership of overlying land. Rights to use non-tributary groundwater are limited to "that quantity of water, exclusive of artificial recharge, underlying the land owned by the applicant or underlying land owned by another" who has consented to the applicant's withdrawal. The annual withdrawal of this type of groundwater is further limited in accordance with a 100-year aquifer life.

Not non-tributary groundwater is groundwater located within one of the Denver Basin aquifers (the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers in the Denver Basin, which extends roughly from Fort Collins to Colorado Springs and from the foothills eastward), but outside the boundaries of a designated basin, the "withdrawal of which will, within one hundred years, deplete the flow of a natural stream…at an annual rate of greater than one-tenth of one percent." Not non-tributary groundwater is also allocated on the basis of land ownership. However, the owner of a not non-tributary well must have a plan for augmentation in place before withdrawing such water.

Designated groundwater is groundwater that would not be available to fulfill surface rights or groundwater that has been the principal water supply for the area for at least 15 years and is not adjacent to a naturally flowing stream. Designated groundwater exists within designated groundwater basins. The Ground Water Commission establishes designated groundwater basins through a notice and hearing procedure when evidence becomes available that groundwater within a specific geographic area meets the above noted criteria. Each designated groundwater basin is administered according to a modified prior appropriation system.

4.3.9 Reuse

Colorado law generally provides for one use of water by the original appropriator. The water that is not consumed by an appropriator's first use is returned to the stream system, either as surface run-off or through subsurface infiltration. Junior appropriators, who are entitled to have stream conditions as they exist at the time of their appropriation, rely on these return flows to fulfill their decreed rights.

Thus, water that is brought into a watershed from a source unconnected with the receiving system termed "foreign" water may be reused by its owner. Foreign water includes non-tributary groundwater introduced into a surface stream as well as water imported from an unconnected stream system ("transmountain water"). Importers of foreign water enjoy rights of reuse that native water appropriators do not have. Such water is deemed "fully consumable" and can be used and reused to extinction so long as the user maintains dominion and control over the water. Dominion and control in this context refers to the intent to recapture or reuse such water, and is not lost when a municipal provider delivers water to a customer's tap or when consumers use such water to irrigate lawns. Dominion over the water is not lost if the importer intends to reuse such water and has some method to track or recapture the water.

In addition, agricultural water rights that are changed to municipal use may also generate fully consumable water that can be used to extinction. This is because the applicant in a change of use proceeding may take credit for, and reuse, the historical CU associated with the prior decreed use. Under this scenario, the amount of water attributable to the historical CU of the senior water right may be used and reused to extinction. Although this is not "foreign water" by definition, it is another source of fully consumable water.

In addition, in some circumstances, applicants for new water rights may obtain decrees that allow a new appropriation to carry with it a "fully consumable" designation that allows the diverted water to be used and reused to extinction if the initial appropriator has, from the beginning, a plan to reuse the water. Recently, challenges to these types of applications have focused on whether the claimed use and reuse to extinction is speculative in nature.

Any water that is deemed fully consumable may be reused to extinction. In practice, municipal exchanges involving fully consumable water (in most instances municipal effluent or lawn irrigation return flow credits), have been a means to reuse fully consumable water. Recently, municipal entities have also started to operate wastewater reclamation projects where fully consumable water, in the form of effluent, is treated to a high standard and used for outdoor irrigation purposes within the municipality's service area. These projects involve pumping the treated, fully consumable effluent to irrigate portions of a service area and thereby reducing demand for municipal potable supplies for irrigation. Reuse projects involving either pumping or exchanges potentially help increase efficiencies and reduce or postpone the overall demand for new water supplies.

4.3.10 Conservation Activities

Conservation practices associated with both municipal and agricultural uses can be an important tool in meeting long-term water supply needs. Demand reduction is an important component of water planning. To the extent that conservation practices are reliable, and/or permanent in nature, such practices can reduce the overall demand for water and thereby reduce any shortfall in supply.

Conservation measures can also take the form of increased efficiencies. However, not all water conserved through more efficient uses corresponds to an increase in overall water supply to a water user. For example, a water user could take steps to eliminate certain phreatophytes and thereby "salvage" additional water. That water, however, is owed to the stream and does not necessarily accrue to the benefit of the specific water user conducting the "salvage" activity, since a water user cannot take credit for a "salvage" activity and thereby divert more water. Salvage water is owed to the stream to be diverted by downstream water users pursuant to the priority system.

SECTION 6—WATER NEEDS ASSESSMENT

6.3.7 South Platte Basin

6.3.7.1 Identified Projects and Processes for M&I, SSI, and Agricultural Users

Major Identified Projects and Processes for the South Platte Basin are summarized in Table 6-36. For reference, Figure 6-11 provides a map of subbasins, counties, and major cities in the basin as referenced throughout this discussion.

Most M&I water providers indicated that they believe they will be able to meet 2030 needs using existing supplies, projects that are now underway, and future plans and projects. Most providers are pursuing enlargement of existing reservoirs and new storage, and consider those actions critical to meeting future needs.

Table 6-36 Major Identified Projects and Processes in South Platte Subbasins

Subbasins (Counties)	Estimated Demand met by Identified Projects and Processes and Additional Conservation (AFY)	Identified Projects and Processes
Denver Metro (Adams, Denver, Jefferson)	108,100	■ Active Conservation ■ Existing supplies ■ Denver Northern Firming ■ Thornton Water Supply and Storage Company transfer ■ Agricultural transfers ■ New storage (including gravel lakes) and reservoir enlargements ■ Reuse for non-potable irrigation of parks and golf courses and other landscaping ■ Treating lower quality water sources
South Metro (Arapahoe, Douglas, Elbert)	38,300	■ Active Conservation ■ Implementation of South Metro Conjunctive Use Plan or alternative ■ Reuter-Hess Reservoir ■ Aurora Long-range Plan ■ East Cherry Creek Plan ■ Agricultural transfers and reuse ■ Additional non-tributary groundwater ■ Reuse for non-potable irrigation of parks and golf courses and other landscaping ■ Indirect potable reuse by blending return flows with raw water supplies ■ Treating lower quality water sources
Upper Mountain (Clear Creek, Gilpin, Park, Teller)	16,500	■ Drilling of exempt wells ■ Cooperative agreements with existing major water providers ■ Development of tributary groundwater supplies and plans for augmentation with agricultural transfers and new storage
High Plains (Cheyenne, Kit Carson, Lincoln, Phillips, Washington, Yuma)	800	■ Additional non-tributary groundwater
Northern (Boulder, Larimer, Weld)	146,500	■ Active Conservation ■ Windy Gap Firming ■ Northern Integrated Supply Plan ■ Halligan and Seaman Reservoirs enlargement ■ New storage including gravel lakes ■ Agricultural transfers ■ CBT acquisition ■ Reuse for non-potable irrigation of parks and golf courses and other landscaping ■ Exchanges ■ Annexation policies ■ Treating lower quality water sources ■ Use of local ditch rights for landscape irrigation
Lower Platte (Logan, Morgan, Sedgwick)	8,900	■ Augmentation of tributary groundwater with agricultural transfers ■ CBT acquisition
TOTAL	**319,100**	

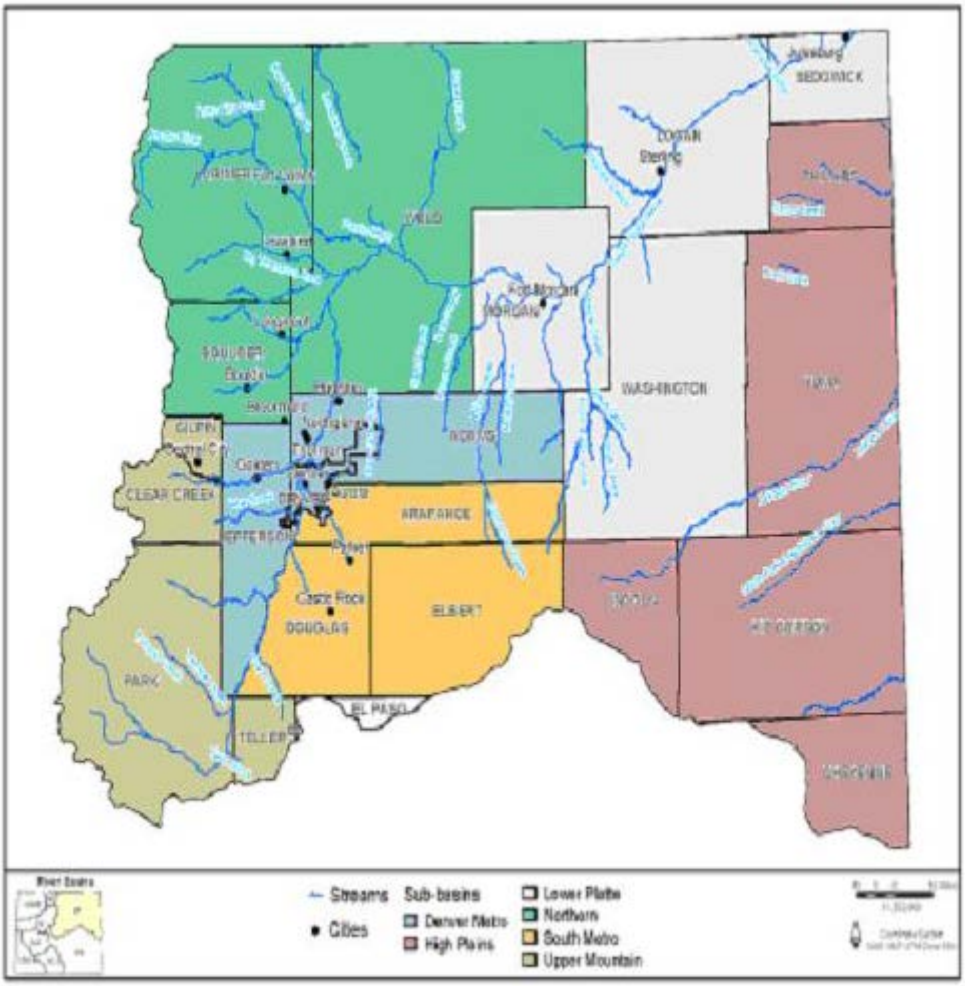


Figure 6-11
South Platte Basin Location Map

Reuse is being pursued by almost all cities that own reusable supplies. The trend toward the use of gravel lake sites that are no longer mined for storage of reusable effluent will expand. The potential for future water rights exchanges of effluent will be considerably less, especially in the Denver and South Metro areas as most of the exchange potential has already been tied up with existing exchange water rights applications. These exchanges, however, will continue to be made when and where feasible. Direct reuse of effluent is largely focused on non-potable uses such as irrigation of parks and golf courses, though other non-potable uses are becoming more prevalent (e.g., power plant cooling water supply). A few cases of indirect potable reuse – intentionally augmenting raw drinking water supplies with treated reclaimed domestic wastewater effluent – are being implemented or planned, and more are likely in the future as water treatment technology advances. The disposal of the waste streams from the treated effluent will be a significant challenge and expense and may limit this option.

While additional conservation is a part of most water providers' plans to meet future water supply needs, most providers do not foresee or propose to implement levels of conservation such as severe

limitations or bans on grass lawns. As in the Arkansas Basin, many providers cite the following as their reasons not to move toward aggressive conservation measures:

- Drought reliability
- Quality of life
- Customer acceptance
- Lawn watering is an indirect source of water supply (can be utilized during periods of drought by restricting water use)
- Operational flexibility

In fact, most providers contacted through SWSI indicated that they would likely acquire additional agricultural rights rather than implement aggressive levels of conservation where the quality of life would be significantly impacted.

Many water providers in the basin's Northern Subbasin indicated that their Identified Projects and Processes include relying on obtaining additional shares of CBT Project water. However, some caution is warranted, in that demand for CBT water will likely exceed the available supply. In addition, much of these transfers of CBT will come from agricultural users that are using the water to firm existing in-basin supplies. As these shares are transferred, the reliability of the overall remaining agricultural supplies will decrease.

Other projects vital to meeting the future needs of Northern Subbasin M&I users are the NCWCD's Northern Integrated Supply Plan (NISP), Windy Gap Firming, and Halligan and Seaman Reservoir enlargements sponsored by the Cities of Fort Collins and Greeley, respectively. The Windy Gap Firming Project, as with the Denver Water Northern system firming project, involve increased diversions of transbasin water from Grand County, which will reduce the availability of water to meet future Grand County M&I, recreational, and environmental needs.

Denver Metro

For Denver Water, the Northern Firming Project, which will increase the reliability of the Moffat Tunnel system, is an integral part of Denver Water's plan to meet future demands. It is important to note that the NCWCD Windy Gap and Denver Firming Projects are, similar to agricultural firming projects proposed in the Gunnison and other basins, designed to increase the reliability of existing supplies and reduce shortages, but are not a new water source. Other providers in the Denver Metro area will rely on existing supplies, reuse, exchanges, gravel lake storage, new storage and reservoir enlargements, and agricultural transfers.

South Metro

The South Metro area has a projected future increased demand of 88,000 AFY. Among the major water providers in this area, Aurora is embarking on its long-range plan to meet future needs as its key Identified Process. This plan will rely heavily on the recapture and reuse of its return flows and agricultural transfers from downstream of the Denver Metro area. The East Cherry Creek Valley Water and Sanitation District is implementing a similar program and the Parker Water and

Sanitation District has recently received a permit for the construction of Reuter-Hess Reservoir. The South Metro Water Supply Study included many of the water providers in Arapahoe and Douglas Counties that currently rely primarily on non-tributary, non-renewable groundwater. As noted in the South Metro Study, the costs of continued reliance on non-renewable Denver Basin aquifer water will increase dramatically as well yields decline and additional wells and infrastructure are needed to maintain current level of groundwater pumping. These costs will not resolve the issue of the long-term reliability of the resource and the ultimate need to develop a renewable source of water. To continue to use as well yields decline, the amount needed ("the gap" between supply and demand) will become significantly larger in the northern portion of the basin. The South

Metro Study identified potential solutions including the development of a CU project, where surface water would be diverted, stored, and treated in wet years to reduce the reliance on groundwater pumping. The South Metro users' needs of approximately 40,000 AF would increase by an additional 40,000 AFY if non-tributary wells fail or become technically or economically infeasible to continue current levels of groundwater pumping in the future. There are no reliable surface water supplies that can be developed from the South Platte using surface water diversions as the sole water supply source. The South Metro Water Providers have indicated that additional alternatives need to be developed for meeting future South Metro water needs.

High Plains

In the High Plains subbasin, continued reliance on non-tributary groundwater supplies is expected to occur to meet future M&I needs. The northern High Plains Ogallala aquifer is anticipated to provide for the limited M&I growth anticipated in this region.

Lower South Platte

The Lower South Platte area will rely on existing rights and agricultural transfers for well augmentation and CBT acquisitions for surface water supply. Water supplies for additional power generation at the Xcel power generating facility in Brush will need to be developed.

Upper Mountain

The Upper Mountain areas primarily rely on groundwater for M&I demands. These areas will have the challenge of the limited physical availability of groundwater. Much of the groundwater is in fractured bedrock and well yields can be highly variable and decline as additional growth occurs. Certain areas in the basin may have self-limiting growth due to the lack of sufficient groundwater and the inability to deliver surface water supplies. Many of these areas already experience reduced well production. Park County has approximately 25,000 pre-1972 platted lots, which are not required to provide augmentation. Many of these lots are platted with high densities. These approved densities may impact well yields, trucked water or onsite storage tanks may be required to meet peak demands for some in-home domestic uses if additional development occurs. Jefferson County is in the process of regulating densities in certain mountain areas in order to prevent over development of the limited groundwater resources.

Agriculture

Based on discussions with South Platte Basin Roundtable members, it is expected that agricultural transfers will continue to occur to meet a portion of the basin's growing M&I needs. This will likely manifest itself through outright purchases, developer donations, and development on irrigated lands.

However, not all agricultural acquisitions can be transferred to existing water intakes. As a result, the use of dual water systems delivering local ditch water through pressurized non-potable water lines will increase.

There is very little irrigated land remaining in the Denver and South Metro areas that can be transferred for M&I use and many of these providers will be looking downstream for agricultural supplies. These supplies will be very expensive to develop as agricultural rights in the South Platte Basin have increased in price and long pipelines of 30 to 70 miles and advanced water treatment facilities will be required to treat these lower quality water sources to potable drinking water standards. The disposal of the waste stream from the advanced water treatment facilities will be a long-term challenge as treatment of these waste streams are very expensive and the waste streams represent up to 20 percent of the total water production.

These agricultural transfers will also require that significant additional storage be constructed to provide carry-over supplies for the non-irrigation season and dry periods. It is estimated that approximately 2 AF of average year agricultural water supplies and 3 AF of storage are needed to produce 1 AF of firm M&I annual yield.

Agricultural transfers may also result in reduced groundwater tables if historic return flows are not made in the location of historic irrigation. These transfers have the potential for impacts on both domestic and agricultural wells.

Agricultural shortages are prevalent and expected to continue throughout the entire basin. The CBT Project was designed to reduce agricultural shortages in the northern area, but the transfers of CBT shares from agricultural to M&I use will increase shortages. The need for augmentation sources for alluvial agricultural wells along the South Platte has become a critical need. As M&I demands increase and providers turn to increased use of their reusable supplies and agricultural transfers, the availability of augmentation supplies for agricultural users decreases and agricultural users cannot compete with M&I providers on the price of augmentation water. Also, the increased use of reusable supplies and potential reduction in return flows from M&I water conservation efforts may result in reduced flows, decreasing available supplies for downstream agricultural users. Significant reductions in irrigated lands will occur in the South Platte unless augmentation supplies are developed for agricultural well augmentation and alternative sources of M&I water are identified.

Water supply gaps for individual water providers were not developed for the South Platte Basin. Most water providers indicated that they believed they would be able to meet 2030 demands. Many of these same providers, however, identified the same sources of future supply. It is unlikely that there are sufficient supplies to meet the acquisition and water development plans of all of the providers, though it cannot be accurately predicted which providers will fall short in their plans.

6.3.7.2 Recreational and Environmental Information

6.3.7.2.1 Flow Considerations

In January 2004, the USFS released a Wild and Scenic River Study Report and Final EIS for 99.5 miles of river including the North Fork of the South Platte River and segments of the South Platte River. All of the South Platte River study corridor and much of the North Fork of the South Platte River study corridor lie within the boundaries of the Pike National Forest (National Forest). Both

areas, however, include many private and local government inholdings. The study corridors also contain a 6.6-mile stretch of the North Fork of the South Platte River that lies outside the National Forest boundary. This section is mostly in private ownership but includes some public lands managed by Denver Water and Jefferson County Open Space.

National Forest System lands in the study corridors are managed in accordance with the Land and Resource Management Plan for the Pike and San Isabel National Forests, Comanche and Cimarron National Grasslands (Forest Plan), approved in November 1984. Pending the outcome of the suitability analysis, Segments A, B, and C in the South Platte study corridor are included in a special management area under the Forest Plan. The special management area, called the "Scenic River Corridor," provides additional protection to preserve the characteristics that made the segments eligible for potential Wild and Scenic designation. Similarly, Segments D and E on the mainstem and Segment H on the North Fork are protected under an interim management plan.

Attributes being protected include the stream's free-flow, water quality, and outstandingly remarkable values (ORVs). The special protection will continue until the study river either is added into the Wild and Scenic River System or is found not suitable for such designation by the USFS, the USDA, or Congress.

If a Wild and Scenic designation is approved, the interim direction would be replaced by a "River Management Plan"; if it isn't approved, the management of the area would be released from special protection and would revert back to the general provisions of the Forest Plan.

Management practices under the current Forest Plan vary greatly by river section, but generally emphasize developed and semi-primitive recreation opportunities, wildlife habitat needs, forage and cover on big game winter ranges, and productive tree stand management.

After the USFS, Denver Water is the next largest land manager or owner in the area. Denver Water's lands are managed for water delivery, dispersed recreation, summer home rentals, and resource protection to ensure high water quality. Over many years, Denver Water had acquired most of the non-federal land along the South Platte from Deckers to the North Fork confluence, and along the North Fork from the confluence to Ferndale, in anticipation that these lands would be inundated by its planned Two Forks Reservoir. Plans for the Two Forks Project were abandoned indefinitely, however, after a 1989 ruling by EPA that the project would violate the CWA.

The USFS intends to protect the outstandingly remarkable values, free-flow, and water quality of eligible segments of the South Platte River through a cooperative process with USFS legal authorities added. The river corridor's ORVs, free-flow, and water quality are to be managed under a federal/state/local government partnership as outlined in the South Platte Protection Plan (SPPP).

The purpose of the SPPP is to protect the ORVs identified by the USFS and preserve water supply functions without designating the river under the Wild and Scenic Rivers Act. These values are historical, fishery, geological, recreational, scenic, and wildlife resources. The SPPP also recognizes that Colorado's Front Range communities rely heavily upon the South Platte for drinking water supply and other M&I uses and that agriculture throughout northeastern Colorado depends heavily on South Platte flows. The ORVs must be protected in the context of preserving these functions as well. The interests of all these communities can be maintained through common dialogue toward an

approach in which the many values on the river – habitat, ecosystem, and human-based – can all be addressed in coordination and balance with one another. Mutual respect for the many important uses is central to the SPPP. It creates a cooperative management structure of local, state, and federal agencies. The underlying principle is no loss of existing or future water supply. The major components of the SPPP are:

- Protect canyons.
- A streamflow management plan, including: no loss of existing or future water supply; minimum outflows from Spinney Mountain, Elevenmile, and Cheesman Reservoirs; ramping (changing gradually) outflow changes from Elevenmile and Cheesman Reservoirs and the Roberts Tunnel; new valves, monitors, and gages; channel work on North Fork to be coordinated with CDOW; public input to annual operating plans; stream channel maintenance and improvement; designation of desirable outcomes; and goals for water suppliers to use as guidance in their operating decisions as follows:
  - Operate Spinney Mountain, Elevenmile, and Cheesman Reservoirs to release stored water to maintain minimum outflow when inflow is low.
  - Operate Spinney Mountain, Elevenmile, and Cheesman Reservoirs for outflows in an optimum range the remainder of the year.
  - Operate Elevenmile and Cheesman Reservoirs outflow for optimum temperatures and ramping of daily temperature fluctuations to benefit fisheries below the dams.
  - Consideration of whitewater and fisheries in Roberts Tunnel discharges, within the limitations described in the Streamflow Management Plan.
  - Revise annual operating plans to limit fluctuations when the potential exists to harm vulnerable life stages of brown or rainbow trout. Future water projects, especially those that would significantly extend bank-full stream conditions, would require an analysis by the project proponent of channel capacity related to adequate protection of fisheries habitat and populations, channel stability, and maintenance of the ecosystem.
- A Management Partnership for Recreation, Wildlife, Scenery, and Other Values.
- Cooperative water quality initiatives would be implemented through the Coalition for the Upper South Platte (CUSP), which is composed of interested local governments, agencies, and parties in the basin. This coalition was originally known as the Upper South Platte Watershed Protection Association.
- Endowment. Front Range local governments and water suppliers would contribute at least $1 million to be spent on the values identified by the USFS.
- Enhancement Board. A coordinating forum, the Friends of the South Platte River, Inc., would provide comments and responses on activities such as land use or land management planning decisions, as well as deciding expenditures from the endowment.

- Withdrawal of 1986 applications for conditional storage rights. Both Denver Water and the Metropolitan Denver Water Authority would withdraw Water Court applications for 780,000 AF of additional storage at the Two Forks Reservoir site.

- Alternative to development of Denver's rights-of-way. Denver Water and environmental groups have proposed a working relationship that could lead to alternative projects and allow Denver Water later to relinquish its 1931 rights-of-way on the South Platte at the Two Forks site. As a demonstration of good faith in pursuing alternative projects, Denver Water would voluntarily impose a moratorium on applications for development of the rights-of-way for a period of 20 years from formal acceptance of the SPPP.

- Provision for limited development. In addition, Denver Water and other present and future water suppliers would continue to have access to the river for operational and maintenance purposes.

Enforcement of the SPPP would be provided by a written agreement between the USFS and those entities making commitments within the SPPP. Public participation would be involved under certain circumstances.

The agency is not completing the Wild and Scenic River suitability study at this time to allow for a period of review of the adequacy of the SPPP. The USFS will, however, amend the Forest Plan to maintain the findings of eligibility and classification to the maximum extent possible under its existing authorities. River corridor management will be monitored and periodically reviewed to ensure continued protection of free-flow, ORVs, and water quality. The monitoring program will rely on current indicators and the standards and guidelines from the Forest Plan.

The development of agreements among participating interests is envisioned as part of implementing the SPPP. However, under the Preferred Alternative, such agreements are not considered mandatory. The Preferred Alternative also considers criteria for determining whether the SPPP is actually being implemented and working properly.

CWCB holds numerous instream flow rights for the major rivers and tributaries in the South Platte Basin (http://cwcb.state.co.us/isf/ Downloads/ Index.htm). These rights are year-round with seasonal variability as reflected in the range of flows shown.

No CWCB instream flow rights have been decreed on the Republican River or the South Fork of the Republican River (http://cwcb.state.co.us/isf/ Downloads/ Index.htm).

6.3.7.2.2 Water Based Recreation

The following federal project reservoirs in the South Platte River and Republican River Basins offer water-based recreational activities in addition to authorized project purposes:

Bonny Reservoir

Bonny Dam and Reservoir provides water for recreation and flood control and are on the South Fork of the Republican River near Hale, Colorado just west of the Kansas border in Yuma County. They are features of the Armel Unit, Upper Republican Division, Pick-Sloan Missouri Basin Program. The reservoir has approximately 2,095 surface acres. Fishing is well known and excellent.

Fishing season is year-round. Camping, hunting, hiking, picnicking, and wildlife viewing can be enjoyed at Bonny Lake State Park. With seasonably warm waters, dependable winds, and sandy beaches, Bonny Lake State Park is a destination for swimmers, water skiers, and windsurfers. Other recreational opportunities include boating and recreational vehicles. Recreation at the site is managed by the CDPOR for the BOR (http://www.recreation.gov/detail.cfm?ID=48 and http://www.usbr.gov/dataweb/html/armel1.html).

Carter Lake

Carter Lake Dam and Reservoir are features of the CBT Project in the South Platte Basin. Its authorized purposes are irrigation, M&I, and recreation. Carter Lake is located in the foothills west of Loveland at an elevation of 5,760 feet. Three miles long and about one mile wide, Carter Lake is a 1,100-acre reservoir surrounded by 1,000 acres of public lands and is popular for fishing, sailing, camping, swimming, scuba diving, rock climbing, and water skiing. Developments include 5 campgrounds with 151 campsites and 3 boat launch ramps. A concession-operated public marina is located at the north end of the lake. A concession for members only (Sail Club) is operated on the northwest shore of the lake. A handicap accessible trail has been constructed at the south shore. Picnicking and wildlife viewing are also available. The reservoir is open year-round. Water levels are low in late summer because of seasonal drawdown. Recreation is managed by Larimer County Parks and Open Lands (http://www.recreation.gov/detail.cfm?ID=49 and http://www.co.larimer.co.us/parks/carter.htm).

Flatiron Reservoir

Flatiron Dam and Reservoir provides water for irrigation, M&I, and recreation, and are located on Chimney Hollow Creek 8 miles southwest of Loveland, Colorado in the South Platte Basin. The dam and reservoir are features of the CBT Project. Facilities include 1 campground with 41 campsites. Total available surface acreage for recreation is 47 acres, surrounded by 200 acres of public land. No boating is allowed. Primary recreational activities include fishing and camping. The primary sport fish available is rainbow trout. Additional recreational opportunities include picnicking and recreational vehicles. Facilities and campground are closed in winter due to ice and snow. Recreation is managed by Larimer County Parks and Open Lands (http://www.recreation.gov/detail.cfm?ID=52 and http://www.co.larimer.co.us/parks/Flatiron.htm).

Horsetooth Reservoir

Horsetooth Reservoir is located in the foothills about 5 miles west of Fort Collins in the South Platte Basin. It provides water for irrigation, M&I, and recreation. The reservoir is at an elevation of 5,430 feet. As part of the CBT Project, it furnishes the main water supply for the Poudre Valley. The reservoir is 6.5 miles long. Developments include 4 campgrounds, 111 campsites, and 7 boat launch ramps. A concession-operated public marina is located at the Inlet Bay area. A concession-operated restaurant is located in the South Bay. A developed public swim beach is located on the west side of the lake. Total water surface available for recreation is approximately 1,900 surface acres, surrounded by 2,000 acres of public land. Primary recreation activities include fishing, power boating, water skiing, and camping. Primary sport fish include rainbow trout, crappie, smallmouth bass, white bass, wiper, largemouth bass, and walleye. Additional recreational opportunities include hiking, picnicking, and wildlife viewing. The reservoir is open year-round. Recreation is managed by Larimer County

Parks and Open Lands (http://www.co.larimer.co.us/parks/Horsetooth.htm and http://www.recreation.gov/detail.cfm?ID=66).

Lake Estes

Lake Estes, a feature of the CBT Project, is formed by Olympus Dam constructed across the Big Thompson River in the South Platte Basin. Its authorized purposes are irrigation, M&I, and recreation. Recreation facilities include a nine-hole golf course, five picnic and associated day-use areas, and a marina. Water surface available for recreation is 185 surface acres. Power boating is limited, but available. Sailing opportunities exist. Fish species available are largely rainbow trout. Facilities are closed in winter due to ice and snow. Additional recreational opportunities include biking, camping, hiking, horseback riding, and wildlife viewing (http://www.recreation.gov/detail.cfm?ID=67).

Mary's Lake

Mary's Lake provides water for irrigation, M&I, and recreation, and is located about 2 miles from Estes Park, in the South Platte Basin. There is a concession-developed campground accommodating 270 campsites, including both RV sites with utility hookups and tent camping sites. Water surface available for recreation is approximately 42 acres. No boating is allowed. Primary recreation activities include camping, fishing, and picnicking. Primary fish species include rainbow trout. Facilities are closed in winter due to ice and snow (http://www.recreation.gov/detail.cfm?ID=88).

Pinewood Lake

Pinewood Lake is located about 12 miles southwest of Loveland, west of Carter Lake, at an elevation of 6,580 feet. It provides water for irrigation, M&I, and recreation. The lake and dam are part of the CBT Project in the South Platte Basin. Developments at the lake include 3 campgrounds with 18 campsites and 1 boat launch ramp. The total available water surface acreage for recreation is about 100 acres surrounded by 327 acres of public land. Only no-wake power boating is allowed. Primary recreational activities include fishing, camping, and boating. Primary sport fish available are rainbow trout. Picnicking and wildlife viewing are also available. Recreation is managed by Larimer County Parks and Open Lands (http://www.co.larimer.co.us/parks/Pinewood.htm and http://www.recreation.gov/detail.cfm?ID=89)

Four sections of the South Platte River have been awarded Gold Medal designation:

- The South Fork downstream from the Highway 285 bridge to the inlet of Antero Reservoir
- The Middle Fork downstream from the Highway 9 bridge (4.9 miles north of Garo) to the confluence of the Middle and South Forks of the South Platte River
- From the Middle and South Forks confluence downstream through Spinney Mountain Reservoir to the buoy line at the inlet of Elevenmile Reservoir
- From Cheesman Reservoir Dam downstream to the North Fork of the South Platte River

The 3-mile section of the South Platte below Cheesman Dam produces more than 500 pounds of fish per surface acre, mostly rainbows 15 to 22 inches.

Spinney Mountain Reservoir, on the South Platte River about 5 miles upstream from Elevenmile Reservoir, also has been awarded Gold Medal designation.

SECTION 8—OPTIONS FOR MEETING FUTURE WATER NEEDS

8.1 Developing Options for Future Water Needs

This section outlines the broad strategies that can be used to address Colorado's water supply needs. These strategies are comprises of different methods or "options" that can be implemented independently or in combination with other options. When several options are combined, the resulting portfolio of options is termed a water supply alternative. A group of individual options that are similar in nature can also be combined into "families of options" as described in the next subsection. Implementation of the Identified Projects and Processes is critical to meeting Colorado's future water demands. Unless these projects and plans move forward, significant additional water supplies, in addition to the remaining gaps projected in Section 6, will be required.

As discussed in Section 6, through the Basin Roundtable process it was determined that approximately 80 percent of Colorado's future water supply needs can be addressed via projects and processes that are being pursued by local water providers. Water supply options that could be used to address the remaining 20 percent and the uncertainty associated with the Identified Projects and Processes were developed during the Basin Roundtable process.

8.2 Families of Options

The Identified Projects and Processes listed in Section 6 and additional future options generally fall under one of the following categories, or "families" of options:

- Water Conservation, including:
  - Active M&I Conservation
  - Agricultural Efficiency Measures

- Agricultural Transfers, including:
  - Permanent Agricultural Transfer
  - Interruptible Agricultural Transfer
  - Rotating Agricultural Transfer Fallowing with Firm

- Yield for Agriculture

- Development of Additional Storage, including:
  - Development of New Storage Facilities
  - Enlargement of Existing Storage Facilities

- Conjunctive Use of Surface Water and Groundwater, including:
  - Bedrock Aquifers
  - Alluvial Aquifers

- M&I Reuse, including:
  - Water Rights Exchanges

  - Non-potable Reuse
  - Indirect Potable Reuse

- Control of Non-Native Phreatophytes

The options included under these categories can be evaluated individually or in combination to help meet the remaining water supply needs for each basin. The likelihood that these options will be successfully implemented and sustainable depends, in part, on the public and institutional support. That support is to a large extent dependent on how well each option meets the SWSI water management objectives. Thus, the above options were evaluated in terms of their performance according to the management objectives and grouped into alternatives.

8.2.1 Conservation

8.2.1.1 Municipal and Industrial Water Conservation

M&I water conservation programs result in improved water use efficiency. M&I water savings occur through the modification of water-using fixtures (e.g., showers, landscapes, cooling towers) and behaviors (e.g., showering time, irrigation schedules, maintenance schedules, etc.). The effects of conservation on M&I water demand are the result of both passive and active water conservation efforts. These conservation efforts, though somewhat unpredictable in their rate of success since they require changes in consumer behavior, can be effective means of reducing water supply needs, with little cost to the community.

8.2.1.2 Evaluating New Supply from M&I Water Conservation

The ability to develop new supplies from water conservation or to carry over conserved water for later use is dependent on the type of water rights used. The potential for conservation must be evaluated on an individual M&I water provider basis, considering the types of water rights owned and the return flow obligations that apply to these water rights.

8.2.1.3 Agricultural Conservation (Efficiency Improvements)

Agricultural conservation or agricultural efficiency implementation is a means to create new water supply that must be carefully evaluated since Colorado water law and interstate compacts may limit or preclude the use of this option to increase supply. This option involves increasing the efficiency of water used for irrigation, so that more of the water that is diverted from streams and rivers or pumped from groundwater meets the direct CU needs for agricultural crops. Typical agricultural efficiency measures include canal lining or the conversion of irrigation practices and technology from flood irrigation to gated pipe or the installation of sprinklers or drip irrigation systems. These measures are designed to reduce the delivery losses that occur as water is diverted from a stream or as groundwater is pumped and delivered to the farm or ranch or as it is applied to the crops.

8.2.2 Agricultural Transfers

Agricultural uses currently account for more than 80 percent of the water diverted and consumed in Colorado. Many agricultural users hold senior water rights that can potentially be changed in use to provide a significant source of M&I water supply. In agricultural transfers, farm land is usually "dried up" or no longer irrigated and the water historically used for irrigation of this land is used for meeting M&I or other needs, such as dedication to CWCB for instream flow purposes. The total

water available under a change of agricultural water rights typically depends on the historical CU of the water for agricultural purposes: this is a measure of the water right for transfer. In addition, the yield of an agricultural water right may depend upon the location of the new use of the water. For example, in general, if the water is to be diverted through the same ditch system as historically, a transfer to M&I use may allow diversions of all of the water previously diverted at the historical farm headgate though the historic CU cannot be increased. The water that may be diverted on a transfer of water from an agricultural use to one out of the basin will be limited to the historical CU. Meanwhile the historical return flows must be maintained; storage may be needed to ensure that other water rights that historically relied on return flows are protected. After the historical return flows have been replicated, it is legal for the transferred "consumable" water to be used and reused to extinction.

8.2.2.1 Permanent Agricultural Transfers

Permanent agricultural transfers involve the permanent acquisition of agricultural water rights, the cessation of irrigation on the historically irrigated lands (dry up), and the transfer or change of a water right to M&I or other uses, such as dedication to the CWCB for instream flow purposes.

8.2.2.2 Interruptible Agricultural Transfers

Interruptible agricultural transfers consist of temporary arrangements where agricultural water rights can be used for other purposes. The agreement with agricultural users allows for the temporary cessation of irrigation so that the water can be used to meet other needs.

8.2.2.3 Rotating Agricultural Transfers with Storage to Firm Agricultural Demands

A third concept was developed during the Basin Roundtable process in an attempt to capture the benefits of a permanent agricultural transfer without the negative impacts. This concept, rotating agricultural transfers with storage to firm agricultural supply consists of a type of interruptible agricultural transfer arrangement involving several agricultural parties and one or more M&I users. Each agricultural user would agree not to irrigate for 1 year out of a set period of years corresponding to the number of agricultural users in the program making the flows available to M&I users. For example, if 10 agricultural users joined the arrangement, each would take their turn not irrigating in 1 year out of 10. The M&I user would obtain a constant annual yield, with this yield coming from a different agricultural user each year. An additional element would be to set aside of a portion of the water from the agricultural lands not irrigated in each year to be placed into storage to firm the yield to the agricultural users that are part of the agreement. This agricultural firming pool would be used in below average years to increase the yield for those agricultural users that are irrigating that year.

8.2.2.4 Water Bank

In addition to permanent agricultural transfers, water banks have been authorized by the Colorado legislature. A pilot program was established in the Arkansas Basin. The water bank provides a mechanism for leasing water on a short-term basis without permanently transferring a water right to another user. Entities with stored water rights have the options to lease their water during times of drought or when it will not be put to beneficial use.

8.2.3 Development of Additional Storage

Storage projects capture water during high flow years and seasons to be used during low flow periods. These storage projects include the construction of new reservoirs, enlargement of existing reservoirs, or rehabilitation of existing reservoirs that have reduced storage volumes due to various structural problems (e.g., spillways unable to meet the current probable maximum flood criteria, etc.). Storage options included in the SWSI process include the construction of new storage facilities to capture legally available flows under a new water rights appropriation, the construction of new storage facilities to maximize the yields of existing water rights, including exchange priorities and conditional storage rights, and the enlargement of existing reservoirs. The rehabilitation of existing reservoirs that are under voluntary or mandatory storage restrictions was evaluated during the Basin Roundtable process. It was determined that while there are many reservoirs with restricted capacities, the total potential storage to be gained from rehabilitation efforts is small in comparison to Colorado's overall need.

8.2.3.1 New Storage Projects

New storage projects include the construction of dam embankments to create on-channel or off-channel reservoirs. Off-channel reservoirs require the construction of diversion or pumping facilities from the river or stream to deliver the diverted water to storage. Another option for the development of new storage is the conversion of gravel pits to gravel lakes. These lakes are formed by reclaiming and lining pits created through gravel mining operations. Diversion or pumping facilities are also required to deliver water to gravel lakes. Storage options will vary greatly in their feasibility, and project considerations, such as firm yield, capital costs, and permitting are site specific.

8.2.3.2 Expansion of Existing Storage Facilities

The expansion of existing storage facilities can be a cost-effective means to develop additional storage. Options for increasing storage in existing facilities include raising dam embankments, dredging of sediments, and deepening reservoirs and raising spillway levels. The expansion of existing storage facilities has several benefits including:

- There are likely to be less environmental and recreational issues than for new storage, since the reservoir already exists.
- Permitting and mitigation requirements may be less difficult than for construction of a new storage facility.
- Existing water rights are not affected if the water is to be stored under a new water right.
- The expansion of storage to capture unappropriated water can potentially reduce the pressure to transfer water from existing uses (i.e., agricultural water) to meet future water needs.
- The expansion of storage for unappropriated water captures an unused resource.
- The expansion of storage helps to maximize compact entitlements for beneficial use within the State of Colorado.

- Overall system efficiencies are increased by minimizing system spills.
- The yields of exchanges and non-potable reuse for irrigation are increased. Maximizing the reuse of consumable return flows requires storage, since return flows occur year-round, but the demand for irrigation is seasonal.
- Storage is required to firm the yield of transfers of agricultural water rights. If additional storage is not constructed, additional agricultural water rights will be needed to ensure adequate supply during below normal runoff conditions. The potential issues and conflicts in expanding existing reservoirs include:
- Environmental and recreation impacts can also occur here depending on the size of facility.
- Expanding existing storage facilities does not diversify water sources and the risks of structural failures or water quality catastrophes are not reduced.
- Permitting and mitigation, though typically less difficult than that for new storage, can still be expensive and lengthy with an uncertain outcome.
- A significant amount of storage may be required to produce an acre-foot of firm yield. The amount of storage required will be basin and water rights specific.
- There are a limited number of reservoirs that can be enlarged. Many reservoirs are not cost-effective to enlarge.
- There is a limited volume of increased storage available through reservoir enlargements.
- The enlargement of existing reservoirs may not be cheaper than new storage. The original dam embankments and spillways, in many instances, were not designed or constructed to current engineering standards. Upgrading the existing facilities to be compatible with an enlargement may not be cost effective.

8.2.4 Conjunctive Use of Surface Water and Groundwater

Colorado's groundwater supplies are abundant but are limited in many areas by physical or legal availability or economic feasibility issues. Physical limitation affects the reliability and sustainability of groundwater as a source of supply. Physical availability measures the amount of water an aquifer can produce, both in the short- and long-term, and primarily affects the sustainability of the resource. Legal availability relates to the amount of water that can be extracted from an aquifer under the water rights administration system that exists in a particular area, and can affect the reliability of the supply. In the context of water supply, aquifers can be categorized as being renewable or non-renewable.

Aquifers that are located adjacent to rivers in the alluvial floodplain deposits usually have a hydrologic interaction with those rivers, and dynamically get water from or discharge water to the rivers throughout their reaches. Aquifers of this type are referred to as tributary aquifers. They usually are unconfined aquifers that are relatively shallow. Tributary aquifers are considered to be a

renewable source of water since they are hydrologically linked to renewable supplies such as precipitation and infiltration of surface water.

The other category of aquifer, non-renewable, is one that is not replenished from renewable sources such as rivers or infiltration of rainfall. Non-renewable aquifers generally are located deep below the land surface, in consolidated bedrock deposits, and would be classified as confined aquifers. A non-renewable aquifer may be capable of producing water reliably under varying climate conditions (wet and dry years); but it may only last 50 to 100 years and would therefore not be considered a sustainable resource. Recharge of non-renewable bedrock aquifers is very slow and withdrawal rates usually exceed recharge. As water levels decline in a non-renewable aquifer additional wells would be required to maintain a given pumping rate. These non-renewable aquifers are unreliable as a permanent, sustainable water supply.

Conjunctive use of surface water and groundwater can maximize the benefits and reliability of both surface water and groundwater sources of supply. In its simplest form, conjunctive use involves using surface water when surface supplies are ample, such as during average to above average runoff conditions, and recharging aquifers with available surface water. When surface water supplies are in short supply, such as during below average runoff conditions, groundwater supplies would be used to a larger degree to meet demands. Both bedrock and alluvial aquifers can be used in a conjunctive use water supply operation by serving as a water storage bank. Deposits are made in times of surface water supply surplus and withdrawals occur when available surface water supply falls short of demand.

8.2.4.1 Bedrock Aquifer Conjunctive Use

Bedrock aquifer conjunctive use involves capturing and using surplus surface water supplies for immediate use or injecting these surplus surface water supplies into the bedrock aquifer through wells. The intent is to extend the life of non-renewable groundwater sources.

8.2.4.2 Alluvial Aquifer Conjunctive Use

Alluvial aquifer conjunctive use involves diverting surplus surface water supplies and recharging the alluvial aquifer. Recharging is typically accomplished by canal infiltration or spreading basins, and then pumping the groundwater when needed as a source of supply or when the timing of accretions to the river system is needed to meet demands (for example, stream depletion requirements or streamflow enhancements).

8.2.5 Municipal and Industrial Reuse

M&I reuse involves a second or consecutive uses of consumable water supplies that have first been used to meet municipal or industrial needs but not fully consumed. The first aspect important to understand in reuse projects is the consumptive and non-consumptive components of water use. Water use is generally divided into CU (i.e., water that is in effect consumed and eliminated from the system) and non-CU (i.e., water returning to the system after use by infiltration into the ground, or water returning to the system as effluent from wastewater treatment plants after use in households). Reuse projects seek to recycle that portion of the water not consumed. M&I consumable return flows can be reused through several methods. Three general types of reuse projects were included for consideration in the SWSI process: water rights exchanges, non-potable reuse and indirect potable reuse.

8.2.5.1 M&I Reuse by Water Rights Exchanges

M&I reuse by water rights exchanges involves the exchange of legally reusable return flows for water diverted at a different location. Water is diverted at one source in exchange for water replaced to downstream users from a different source. In an M&I reuse exchange, the amount of non-CU water returned to the system, e.g., via effluent flows and/or return flows from landscape irrigation, depends on the CU associated with the demand (i.e., the higher the CU, the lower the percent of total diversions that can be reused).

The non-CU water can be reused multiple times, theoretically to extinction, with the total available water reduced with each application, since each time the water is diverted for reuse, a portion of it is consumed by the use. Increases in yield that can be achieved through the successive use and reuse of the return flows to extinction. For example, if there are no return flows from the use of 1 AF of consumable water, then there is no additional yield and the total yield is one acre-foot. If 50 percent of the return flows from an M&I use of consumable water were exchanged and the return flows from each successive use used to extinction, the total yield realized from 1 AF of consumable water is 1.6 AF. This is based on an assumed M&I CU of 35 percent and return flows of 65 percent.

8.2.5.2 Non-potable Reuse

Non-potable reuse involves the capture and use of legally reusable return flows for the irrigation of urban landscapes or for industrial uses such as cooling or process water. Since return flows from landscape irrigation are hard to capture in one location, non-potable reuse to date has involved the reuse of consumable effluent discharged from wastewater treatment facilities.

The effluent undergoes additional treatment to meet non-potable reuse standards. This treatment usually involves filtration and additional disinfection. As noted, it is infeasible to capture return flows from landscape irrigation, though additional yield could be achieved if the landscape irrigation return flow points and amounts are identified and exchanged to upstream points.

8.2.5.3 Indirect Potable Reuse

Indirect potable reuse involves the capture of legally reusable return flows and reintroduction of these captured flows into the municipal raw water supply. The return flows that are captured may have been discharged to a river or stream and mixed with other waters. Other options include the capture of treated wastewater effluent and additional treatment. The captured flows are then reintroduced into the M&I raw water supply system. The water may require advanced water treatment methods beyond the existing level of treatment used for the current water supply before the recaptured water was introduced into the raw water supply.

8.2.6 Control of Non-Native Phreatophytes

This option would consist of a basinwide or a focused-area program for the removal and control of non-native phreatophytes that consume water that could otherwise be used by any of the basin users: agricultural, M&I, recreational, or environmental. Non-native phreatophytes are invasive plant species that consume water. Of particular concern in Colorado are tamarisk trees. Methods of removal include: mechanical removal, prescribed burning, biological control, and herbicide application. While state and federal programs are beginning to evaluate phreatophyte control options in more depth, the costs and benefits (e.g., yields) of phreatophyte control programs are largely

unknown at this time. Demonstration projects are planned in the Rio Grande and Arkansas Basins, and USGS is updating estimates of potential water savings.

SECTION 10—BASIN-SPECIFIC OPTIONS

Section 6 of this report presented the future water supply options that water providers are pursuing to meet their needs. SWSI has termed these options "Identified Projects and Processes" and it is estimated, under a best case scenario, that approximately 80 percent of

Colorado's future needs can be met by implementation of these options. However, that leaves a remaining gap of 20 percent (118,200 AF). In addition, if some portion of the Identified Projects and Processes are not successfully implemented, it may be prudent to have some conceptual solutions that could be pursued. The types of options available were described in Section 8. This section outlines some of the basin-specific options, which when combined are termed Alternatives, that could help address unmet future water supply needs.

10.1 Overview of Basin-Specific Issues

In each of the eight river basins, various key activities related to water supply planning and basin specific issues were identified during the SWSI process and Basin Roundtable Technical Meetings. This section summarizes the basin specific activities and issues related to water planning and water resource management and environmental and recreational options. In addition, existing conditional storage rights and restricted reservoir sites in each basin were identified and discussed during the process and are also summarized.

10.1.1 Conditional Storage Rights

Consistent with SWSI's objective of identifying various water management possibilities, the concepts of enhancing water supplies throughout Colorado by perfecting conditional storage rights and rehabilitating existing reservoirs were explored. A conditional water right is not an absolute water right, and therefore has not been put to beneficial use. A conditional storage right must have two elements in order to exist. First, there must be an intent, and secondly, an act. An intent is a plan that includes diligently proceeding with actions until eventually the full beneficial use of the water is realized. An act could be as simple as staking the location of the structure. Cities are given more flexibility in this process, having only to show expected requirements based on validated growth projections. However, because some conditional storage rights holders have priority dates senior to existing absolute junior rights, if they fully exercise their rights, junior water rights holders would be affected. Conditional storage rights can therefore play an important role in the development of the state's water resources if they were to be fully implemented. Conditional storage rights are discussed in more detail under each basin.

10.1.2 Restricted Reservoirs and Potential New Storage Sites

Periodically, the SEO compiles a list of dams that are on restrictions throughout the state. This list, current as of August 2004 in this report, describes the various reservoirs in the state that are in severe disrepair, have inadequate spillways, spillway erosion, or other structural defects. These facilities have restricted storage levels less than the normal operating capacity. If these reservoirs were to be rehabilitated and storage restrictions removed, additional water could be stored and

available to meet increased demands. In addition to perfecting conditional storage rights and rehabilitating restricted reservoir sites, hundreds of potential reservoir sites that exist throughout the state could also aid in water supply planning efforts. After passage of a 1986 House Bill, the CWCB began compiling an inventory of these potential damsites, as well as maintaining and updating it periodically. A minimum potential storage volume of 20,000 AF or more was selected when developing the inventory. A review of the State Engineer's water rights tabulation, publicly available literature, and input from consulting engineers, Division Engineers, and various Water Conservancy Districts were used to compose the list. Included in the inventory is a review of the State Engineer's Reservoir Water Rights Tabulations, which identified sites with conditional decrees equal to or greater than 5,000 AF.

10.1.9 South Platte Basin

10.1.9.1 South Platte Basin Gap Analysis Issues

As presented in Section 6, the gap analysis process presented at the Basin Roundtable Technical Meetings provided information on the Identified Projects and Processes that M&I water providers are reasonably confident of implementing to meet 2030 water demands. Key activities related to water supply planning and basin specific issues raised throughout the meetings and SWSI process with respect to M&I and SSI demands in the South Platte Basin include the following:

- The South Platte is a diverse and heavily urbanized basin. Agriculture is still the dominant water use but rapid changes are occurring and the impacts to rural communities are a key concern.
- Turf based recreation (soccer, baseball, golf, football), parks, and urban landscape is very important to the economy and an important component to quality of life.
- Many of the major surface water providers believe they will be able to meet 2030 needs through existing supplies, projects underway, and future plans and projects.
- New storage and enlargement of existing reservoirs will be major components in meeting 2030 demands.
- Approximately 2 to 3 AF of storage is needed to carry over agricultural water rights transferred for use by M&I users in the non-irrigation season and for below-average runoff years.
- Reuse is being pursued by most providers that have reusable supplies through implementation of the following:
  - Water rights exchanges.
  - Non-potable use for irrigation of parks and golf courses.
  - Groundwater recharge.
  - Gravel lake storage for storing reusable return flows for later use for exchange or non potable irrigation.

- Water conservation is a part of most water providers' plans to meet future water supply needs.
- Most providers do not foresee or propose to implement extreme (Level 5) conservation due to concerns over:
  - Water demand hardening and the related impact on reliability of supply during droughts.
  - Quality of life impacts as a result of financial impacts and/or reduced landscaping.
  - Customer acceptance of very high water rates or the inability to landscape as they desire.
  - Lawn watering is a source of water supply and can be used during periods of drought by restricting water use.
- Most providers indicated they would acquire additional agricultural rights to meet future demands rather than implement extreme levels of conservation that would have adverse impacts on their customers.
- Water reuse and conservation will put added pressure on agriculture as return flows diminish.
- Return flows from M&I lawn watering are used to maintain historical agricultural return flow requirements from transferred agricultural rights. Reducing these return lawns through water conservation may result in the need for the M&I provider to acquire other sources of water to maintain the required return flows.
- Competition for water is fierce and it is unclear how much competition there is for the same water supplies.
- The lack of any new major water storage in the last 20 years has led to the use of non-renewable groundwater in Douglas, Arapahoe, and northern El Paso Counties (El Paso County is in the Arkansas Basin). Explosive growth in these counties coupled with the lack of surface water supplies led to the creation of multiple small water districts and makes coordinated water development a challenge and less efficient, especially in light of limited renewable surface water supplies.

Agricultural issues noted throughout SWSI in the South Platte Basin include:

- There are average annual shortages throughout the basin.
- The continued pressure on the transfer of Colorado Big Thompson units from agriculture to M&I will further increase shortages as CBT water is a supplemental agricultural supply.
- The Lower South Platte groundwater users need alternatives for developing augmentation supplies for irrigation wells. Over 60,000 acres of currently irrigated lands may no longer be irrigated due to recent well augmentation requirements.

10.1.9.2 South Platte Basin Supply Availability Issues

In the South Platte Basin, the following issues were identified regarding supply availability:

- The South Platte River Compact allows further development of available flows.
- The success of an endangered species program is critical to help protect current and future uses.
- By 2030, there will be full utilization of:
  - Existing rights.
  - Transbasin diversions.
- RICDs and CWCB instream flow water rights may impact the ability to manage water supplies upstream of these water rights.
- Development of conditional water rights will continue.
- Groundwater recharge projects will expand.
- Agricultural efficiency, especially conversion to sprinklers, is reducing return flows. Changes in irrigation efficiency will affect return flow patterns.
- Normal agricultural calls may become more senior, resulting in an increase in the number of junior water rights that are out of priority. Factors contributing to this include:
  - Development of gravel lake storage to capture M&I return flows.
  - Increased reuse of M&I return flows.
  - Increased irrigation efficiencies.
- Winter calls can be expected to increase, reducing free river periods. Increased winter calls may reduce the timeframe in which recharge can take place.
- Water supply estimates in the South Platte Basin are reconnaissance level. A DSS is not available to analyze all of the potential interactions of M&I development of conditional storage rights and reduced return flows as described above.

10.1.9.3 South Platte Basin Summary of Conditional Storage Rights

To portray the conditional storage rights present in the South Platte Basin, the area was described using water districts as shown in Figure 10-24. The 15 water districts in the South Platte Basin can also be described using the main stream systems, which are shown in Table 10-19.

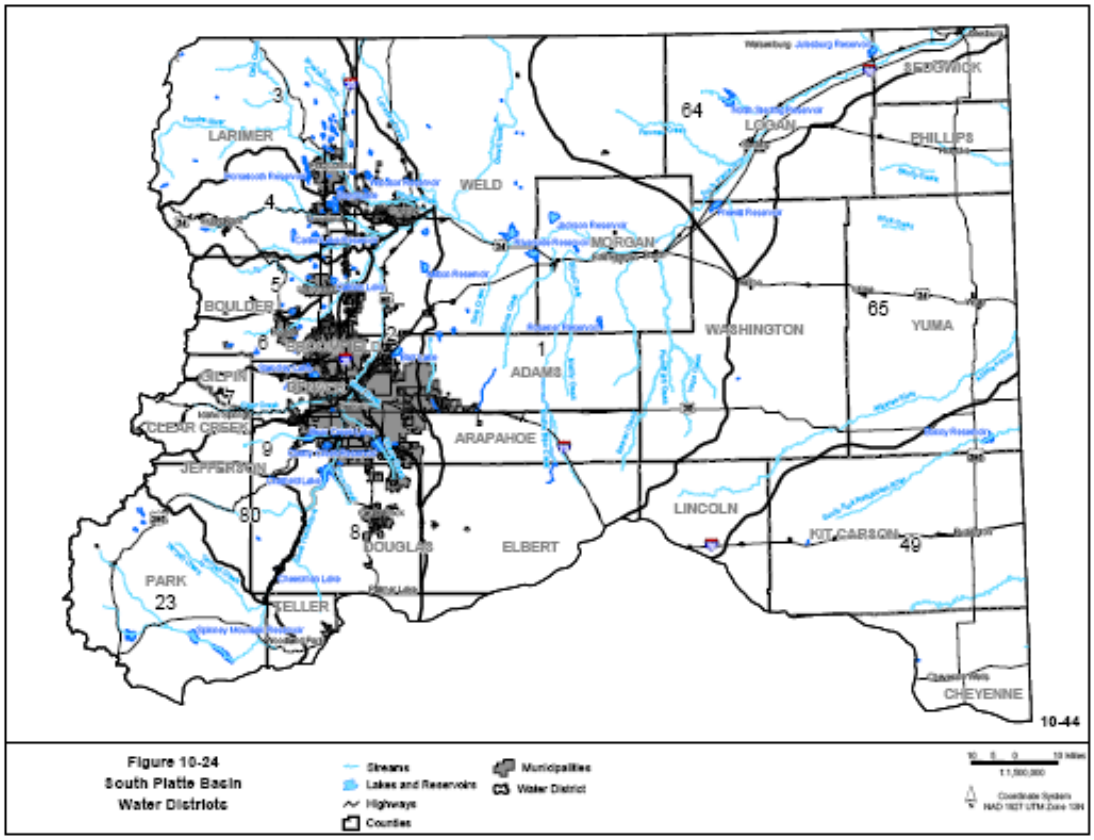


Figure 10-24
South Platte Basin
Water Districts

Table 10-19 South Platte Basin Water Districts and Associated Stream Names

Water District	Stream Name
1	Lost/Kiowa/Bijou/Crow Creeks and S. Platte River
2	S. Platte River
3	Poudre River
4	Big/Little Thompson Rivers
5	St. Vrain Creek
6	Boulder Creek
7	Clear Creek
8	S. Platte River
9	Bear Creek
23	Middle Fork S. Platte River
49	S. Fork Republican River
64	S. Platte River
65	Arikaree River
80	N. Fork S. Platte River
101	S. Platte River

Various water districts in the South Platte Basin contain conditional storage rights that date back to the early 1900s and extend to present day. As shown in Table 10-20 there are 3.6 million AF of conditional storage rights in the basin. The numbers presented in this table describe the total volume of conditional rights by priority time period and not the number of individually decreed conditional rights. These priority time periods are based on adjudication dates and used solely for the purpose of aggregating the numerous conditional rights into a table for presentation. Water District 1, followed by District 8 in the South Platte Basin, has the largest volume of conditional storage rights. This is depicted in Table 10-20. Water District 1 has almost 1.4 million AF of conditional storage rights and Water District 8 has nearly 638,000 AF. The most recent priority time period of between 1980 and 2002 has the largest amount of conditional storage rights in the South Platte, about 1.8 million AF, which far exceeds available supplies. The 1960 to 1980 period follows with a total of approximately 892,000 AF. A map of the locations of the conditional storage rights in the South Platte Basin is shown in Figure 10-26. Different colored circles are used to represent the total volume of conditional rights that each location holds. Most of the rights are held in the western portion of the basin and along Interstate 76. This figure also shows the locations of potential damsites in the South Platte Basin, as discussed in Section 10.1.9.4 below. In the South Platte Basin, many M&I providers have reservoir enlargement plans that will help them grow into existing rights and allow development of some existing conditional water rights.

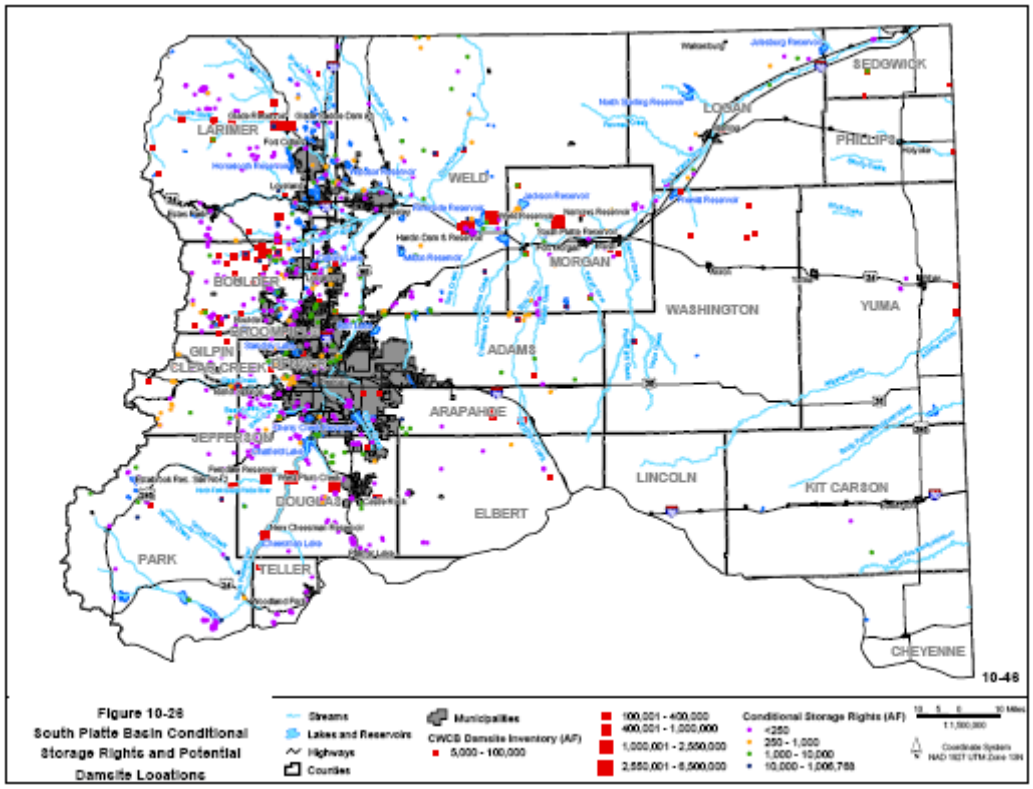
Table 10-20 Volume of Conditional Storage Rights by Priority (AF) in the South Platte Basin

Water District	Stream Name	1900-1920	1920-1940	1940-1960	1960-1980	1980-2002	Total
1	Lost/Kiowa/Bijou/Crow Creeks and S. Platte River	250,012	6,358	0	413,368	719,406	1,389,144
2	S. Platte River	1,596	20,965	0	16,682	78,055	117,298
3	Poudre River	0	0	29,472	5,184	384,397	419,053
4	Big/Little Thompson Rivers	0	19,926	0	1,703	21,421	43,050
5	St. Vrain Creek	1,677	0	13,594	71,649	170,871	257,791
6	Boulder Creek	4,978	4,755	83,870	34,985	22,917	151,505
7	Clear Creek	18,345	0	180	18,774	175,154	212,453
8	S. Platte River	0	336,368	20	220,620	80,921	637,929
9	Bear Creek	1,834	36	0	5,006	7,915	14,791
23	Middle Fork S. Platte River	327	111,423	0	74,306	133,578	319,634
49	S. Fork Republican River	0	0	0	75	0	75
64	S. Platte River	0	0	0	14,301	8,839	23,140
65	Arikaree River	0	0	0	0	330	330
80	N. Fork S. Platte River	0	1,938	0	15,052	17	17,007
Total		278,769	501,769	127,136	891,705	1,803,821	3,603,200

10.1.9.4 South Platte Basin Summary of Restricted Reservoirs and Potential Storage Sites

The total volume of restricted storage in the basin is 48,929 AF. Eighteen restricted reservoirs are located within Water District 1, totaling about 25,000 AF of lost storage, and two reservoirs are located in Water District 64 with slightly less than 10,000 AF of lost storage. More than 7,000 AF of storage is lost in the seven restricted reservoirs in Water District 23. Given the limited water supply availability in the South Platte Basin, recovery of storage lost to restrictions should be explored in more detail. While the other water districts in the South Platte Basin have restricted damsites, except Districts 49, 80, and 101, each district has less than 5,000 AF of potential storage if repairs were made. Figure 10-26 shows the locations of potential damsites identified by the CWCB in the South Platte Basin, along with the conditional storage rights locations. Different colored circles are used to

represent the total volume of conditional rights that each location holds. Potential damsites are classified by total potential storage.



10.3.7 South Platte Basin

Water needs in the South Platte Basin were identified and characterized in Section 6. While about 78 percent of the basin's increased M&I needs could be met by the Identified Projects and Processes described in that section (if all of the Identified Projects and Processes are fully successful), the remaining gap for M&I, agricultural, environmental, and recreational needs will need to be addressed by additional water management solutions. As discussed in Section 6, the size of the gap will depend on the degree of uncertainty and successful implementation of the Identified Projects and Processes.

A list of projects or water management options for further consideration in meeting the basin's future water needs is presented in Table 10-32. This list was developed and refined through the series of four Basin Roundtable Technical Meetings held in the South Platte Basin, augmented by additional input from the Basin Advisors, Basin Roundtable members, and individual entities throughout the basin. This list represents a broad range of options, both in terms of the types of solutions and their degree of development. In many cases, the options are at a conceptual stage of development and therefore have relatively little information available about their storage size, yield, or other characteristics. In other cases, a concept for meeting needs in more than one location in the basin was identified – such as the generalized items termed "control of non-native phreatophytes." However, each option listed was brought forth in SWSI as a potential means toward meeting future water needs in the basin. In most cases, additional studies or information would be needed to advance these water management options toward implementation. Given the diversity of the South

Platte Basin, the types of water management solutions proposed can be expected to follow the land use patterns in the basin. For example, agricultural solutions will be focused largely on the agricultural lands in the Lower Platte and Northern subbasins, while M&I solutions will focus more intensively on the higher-population areas of the Front Range (Northern, Denver Metro, and South Metro subbasins).

Table 10-32 Potential Future South Platte Basin Water Management Options

Project	Sponsor	Type of Project	Additional Storage (AF)	Additional Yield (AFY)	Project Purpose and Notes
Standley Lake Enlargement	City of Northglenn	Additional Storage	up to 18,000	up to 6,000	Purpose is to firm the water supply for M&I users. Northglenn has an existing gap that could be addressed through additional storage. Other parties may participate; Yield varies depending upon participants
Tamarack Plan	State of Colorado	Groundwater Recharge and Conjunctive Use	Not Available	10,000	Managed groundwater recharge projects to reregulate flows in a manner that is consistent with the flow-related goals of the Platte River Recovery Implementation Program.
Julesburg Enlargement	CWCB	Additional Storage	15,000	7,800	Addresses lower basin agricultural needs.
Johnson Reservoir	CWCB	Additional Storage	10,600	7,800	Addresses lower basin agricultural needs.
Harmony Ditch West	CWCB	Additional Storage	10,000	6,000	Addresses lower basin agricultural needs.
Groundwater Storage / Alluvial Storage	None	Conjunctive Use of Groundwater	Not Applicable	Not Available	Ongoing programs, new projects anticipated. Could benefit all users and M&I, agricultural, environmental, and recreational.
Flow Control Program between Reservoirs	None	Re-operations	Not Applicable	Not Available	Provide for management of flows between reservoirs for recreational and environmental uses without impact yields to M&I and agricultural users.
Control of Non-Native Phreatophytes	None	Control of non-native phreatophytes	Not Applicable	Not Available	—
Reallocation of Storage in Chatfield Reservoir	Numerous Parties	Reallocation of flood control storage.	20,000	Not Available	Reallocation of flood control storage to allow storage for M&I purposes. Flow management in the South Platte through Denver.
Pawnee Creek Project/Storage Site	None	Additional Storage	Not Available	Not Available	Address agricultural shortages in Lower Platte.
South Metro Water Supply Project	South Metro Water Providers	Storage and non-tributary groundwater conjunctive use		$2-4 billion	Development of new storage to capture South Platte and West Slope water and conjunctive use with non-tributary groundwater.

Specifically, the need to develop additional water management solutions in the South Platte Basin for M&I demands is based on the following:

- Potential for failure of the Identified Projects and Processes to address in-basin needs
- Some future growth areas do not have identified water planning processes
- Limitations in the reliability and sustainability of non-tributary groundwater
- Limitations in the ability to reliably store water under junior water right appropriations
- Competition for the same supplies
- Potential for greater than projected growth

- The success of the proposed Endangered Species Program.
- The potential "domino effect" of increased M&I reuse of consumable supplies, resulting in reduced downstream flows and more senior calls
- Potential impacts of climate change

Based on discussion with the South Platte Basin Roundtable members and the evaluation of options, the following types of options generally meet the objectives of the South Platte Basin Roundtable members and could be further evaluated for their role in addressing the remaining M&I gap in the South Platte Basin:

- Construct new storage to maximize existing water rights and conditional storage rights
- Reservoir enlargements to maximize existing water rights and conditional storage rights
- Additional conservation, possibly coupled with additional storage to enhance reliability
- Rotating Agricultural Transfers
- Agricultural conservation (efficiency improvements) while recognizing the potential negative effects on return flows. Specific options identified through the Basin Roundtable process were cataloged in Table 10-32.

Agricultural water solutions could address the following concerns:

- Recharge plans may be limited in future
- Need for additional storage to "firm up" agricultural water supplies and/or to "firm up" augmentation water
- Increased river calls in the lower river due to reduced return flows and M&I reuse, which will impact both municipal water providers and agriculture
- Potential impacts of climate change

Irrigated agricultural acreage in the South Platte Basin is expected to decline significantly over the course of the next 30 years. Development of irrigated lands, transfer to M&I use, and the inability to augment well pumping will all contribute to this decline. Meeting the South Platte Basin's future agricultural needs will focus primarily on meeting existing needs and firming supplies available to existing agricultural users rather than expanding irrigated acreage. Water management solutions that could be used to support these goals include:

- Construct new storage
- Reservoir enlargements or dredging of existing reservoirs
- Removal of storage restrictions

- Additional development of alluvial aquifer recharge projects
- Improvements in agricultural efficiency, using caution to avoid impacts on downstream users of return flows
- Agricultural purchase of more senior water rights to reduce river calls or provide for well augmentation
- Development of a single entity to coordinate proposed augmentation activities and for the agricultural wells, to maximize the yield of the augmentation plans

Environmental and recreational water management solutions were discussed conceptually in SWSI, with many of the concepts aligning with the approaches (such as "conserve, protect, and restore"). Specific water management solutions discussed through the Basin Roundtable process toward achieving environmental and recreational goals are presented below.

- Tarryall Reservoir Enlargement—CDOW-proposed options to use the additional storage in potential exchange agreements with other entities such as Aurora, Denver, and Centennial. Cheesman and Strontia Springs Reservoirs could enhance sport fishery of Tarryall Creek and South Platte River and wetland development in South Park. CDOW identified this as a high-priority project, but it currently is in the conceptual stages of development.
- Montgomery Reservoir Enlargement—A second CDOW-proposed option involves storing transbasin water rights from the Blue River or South Platte River to improve stream flows and enhance sport fishery in the Middle Fork and mainstem of the South Platte River. Considered a medium priority by CDOW, it is currently in the conceptual stages of development.
- Tamarack Project—This ongoing project is geared toward enhancing native and threatened and endangered species habitats in Colorado and Nebraska by creating pump back recharge river credits and timed flow augmentation. It is an important component of the Three State Agreement between Colorado, Nebraska, and Wyoming, and the DOI, and is considered a high priority by CDOW for ongoing implementation.

SWSI participants also suggested that in any water management action, project sponsors and participants should seek to identify opportunities to return to more natural hydrologic flow patterns in the basin. An example of voluntary efforts to improve flows for environmental purposes is the Upper South Platte River Flow Management Agreement.

SOUTH METRO WATER SUPPLY STUDY

Purpose of the Study

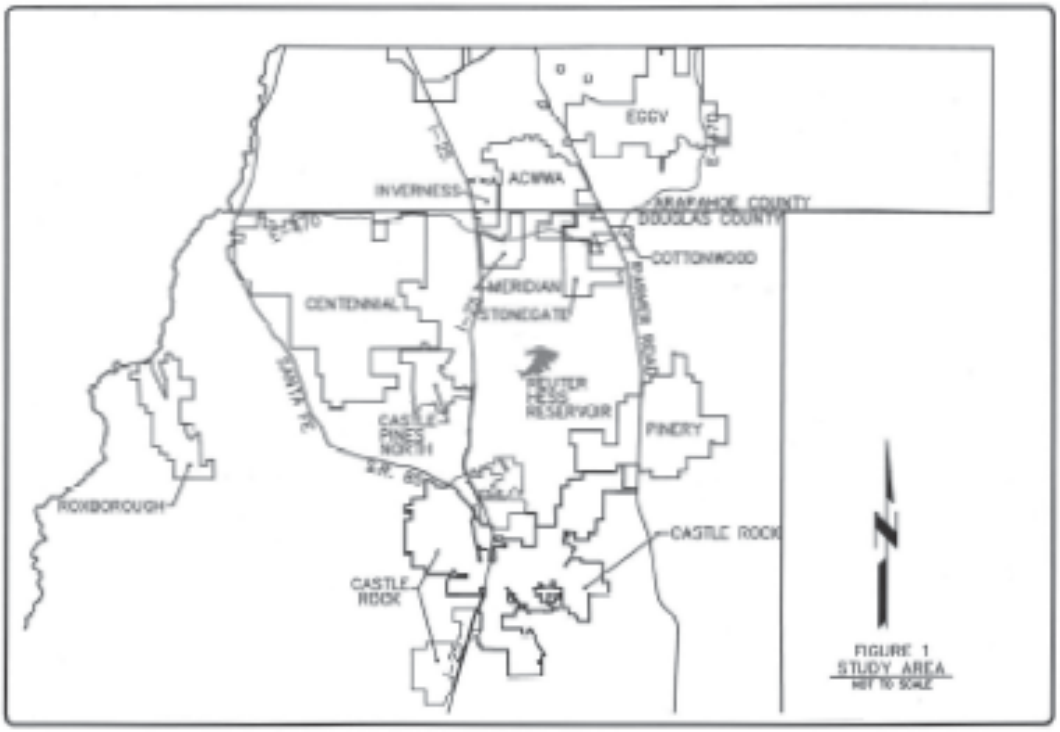
The purpose of this study was to investigate water supply alternatives for the South Metro area through the year 2050.

Currently, the South Metro area's primary source of water supply is the Denver Basin Aquifers, a large ground water reserve underneath the land within the area's boundaries. The question driving this study is whether this water supply source can adequately meet the long term demands of the existing population as well as the demands associated with continued population growth.

Additionally, the study investigates whether there are benefits to using surface supplies from the South Platte and Blue River during wet years, along with ground water. This concept, called "conjunctive use," would help preserve ground water supplies by making use of renewable surface water in years when it is plentiful.

The Study Area

The Study Area includes the service areas of the water providers located in the north half of Douglas County. This area includes the Town of Castle Rock north to the Douglas/Arapahoe County boundary, with the exception of most of the Town of Parker. In addition, much of the urbanized portion of Arapahoe County, located east of I-25, is included. The Study Area is shown in Figure 1.



Population

The challenging water situation in the South Metro Study Area is fueled by extremely rapid population growth during the last 25 years and projected rapid growth in the future. During the 1990's, Douglas County had the nation's fastest growth rate. Between 1990 and 2000, population jumped by 191%. Douglas County growth continues at a similar rate today.

In addition, the Arapahoe County portion of the Study Area includes the rapid growth area of the city of Centennial. The growth rate in this portion of Arapahoe County has been similar to that of Douglas County.

The current and estimated population of the Study Area is shown in Table 1. While the study period extends to year 2050, full development occurs by year 2040.

Table 1
Study Area Population Projections

Year 2000	Year 2020	Year 2040
179,000	359,000	406,000

Water Supply Sources

Water supplies for the Study Area were largely developed during the last 25 years, long after the best sources of surface water from the South Platte River and its tributaries were claimed. While the Study Area has limited surface water from Cherry Creek, Plum Creek and the South Platte River, this water represents only about 25% of the water needed for the area in 2050.

The largest source of available water in the Study Area is deep ground water in the Denver Basin. While this is currently a plentiful source of water, in the future it will be much more difficult and costly to produce at the rates required to serve urban areas. Moreover, the amount of water naturally recharging the deep ground water is very small compared to the water being pumped. Therefore, the volume of water in the aquifer is slowly being depleted. Due to concerns about the long-term viability of the deep ground water, water providers in the South Metro area have taken measures to preserve the deep ground water whenever possible, including pursuing renewable surface water supplies when available.

In general, these water providers have maximized the use of surface water, adopted programs of water conservation, and developed a significant amount of reusable water -- either through augmentation (diverting water in exchange for water returned to the stream) or through non-potable irrigation (water not suitable for drinking). Still, the South Metro area remains heavily reliant upon deep nontributary ground water (water not connected to the surface stream).

Water Demand

The current and future water demands for the Study Area are shown in Table 2. Full development of the area is expected to occur by 2040. These projections are based upon the historical water use of each of the water providers in the study and include residential and commercial uses and system losses, forming the basis for the analysis in this report.

Table 2
Study Area Water Demand Projections (Acre-feet)

Year 2000	Year 2020	Year 2040
42,323	81,732	92,213

Alternatives

All of the water providers in the South Metro area currently have water conservation and reuse (recycling of water) programs in place. However, the water providers recognize that more aggressive water conservation and reuse will be needed in the future. Each alternative described below assumes a 15% reduction in outdoor water use, along with expanded reuse wherever practical.

Alternative 1A - Status Quo.

This alternative investigates the possibility of meeting most of the Study Area's future demand by drilling additional wells in the Denver Basin Aquifers and increasing the area's dependence on deep ground water. It identifies the facilities that will be required and examines the costs of producing additional deep ground water supplies. Today, summer peak season demands are met by pumping the deep ground water at high rates. Alternative 1A assumes that peak demands will continue to be met in this manner.

This alternative assumes that water providers will use their existing water rights in the Denver Basin Aquifers. It further assumes that if these water rights are not sufficient to meet demand, more-deep ground water will be purchased from nearby locations. Alternative 1A also looks at the infrastructure required to produce and deliver the deep ground water to customers (e.g., wells, treatment facilities and delivery pipelines). In cases where deep ground water would need to be purchased from locations outside the service area, well development and the transmission system required to deliver that water to the water provider's system is identified.

Alternative 1B - Status Quo with Storage for Peaking.

Alternative 1B is identical to Alternative 1A except in the method for meeting peak demands. In Alternative 1B, instead of using wells to meet demands during very high summer peak periods (as in Alternative 1A), deep ground water would be pumped on a year-round basis at a much lower rate. During the winter, when the water pumped would be greater than customer demand, the excess would be pumped to new storage reservoirs. In the summer months, when customer demand exceeds the volume of water pumped, water would be withdrawn from storage to meet demand.

Alternative 1B would require far fewer wells than 1A, but storage reservoirs would be needed. In addition, water stored in open reservoirs would require water treatment before being used in the water system. This alternative considers these changes in infrastructure requirements, as well as the associated costs.

Alternative 2 - Non-Tributary Ground Water with Maximum Reuse.

Alternative 2 is a variation of Alternative 1B that assumes all available water that is legally reusable would be reused to extinction regardless of costs and other issues. In Alternatives 1A and 1B, some of the reusable water supplies in the East Cherry Creek Valley Water and Sanitation District, the Town of Castle Rock, the Meridian Metropolitan District and the Roxborough Park Metropolitan District were assumed not to be fully developed.

While Alternative 2 produces a number of additional water reuse opportunities, institutional constraints -- including existing contracts -- may preclude some of these opportunities from being realized.

Alternative 3A - Conjunctive Use with Borrowing from Denver Water Storage.

Alternatives 1A, 1B, and 2 provide strategies to meet demands for the South Metro area without the import of surface water supplies. The "conjunctive use" alternatives, 3A and 3B, examine whether deep ground water can be effectively used conjunctively with surface supplies from the South Platte and Blue River. Conjunctive use alternatives would preserve ground water supplies by making use of renewable surface water in years that it is plentiful.

Since the conjunctive use alternatives, 3A and 3B, each rely on meeting demand with local water supplies alone in dry years, all of the infrastructure of either Alternative 1A, 1B, or 2 needs to be included as part of Alternatives 3A and 3B, except that the number of additional wells under Alternatives 3A and 3B would be fewer because of lower average ground water pumping.

Alternative 3A is a regional approach to water supply development. Water would be imported from the South Platte River and Blue River in wet years - when surface supplies are plentiful - through Denver Water's existing raw water system to the west side of the South Metro area. This water would then be delivered to South Metro water providers through a new pipeline distribution system. Alternative 3A would require limited use of Denver Water's storage capabilities to increase the volume of surface water captured.

In dry years, South Metro water providers would continue to use their existing sources of supply without diverting any water from Denver Water's raw water system. In wet years, water would be borrowed from Denver Water's surface water reservoirs prior to runoff (during the late winter and early spring months) for delivery to Douglas County. This would take place at a time when there normally would not be any water available to a junior water right. The timing and amount of reservoir releases would be based upon two things: 1) Snow pack accumulations during the late winter and early spring; and 2) Denver Water's reservoir levels.

The effect of Alternative 3A would be to lower water levels in the Cheesman and Dillon reservoirs during the late winter and early spring, thereby increasing the potential to capture additional water at these locations during high runoff periods. In years with sufficient above average runoff, water would continue to be delivered to Douglas County via direct diversions under a junior water right at the same time that Denver's reservoirs would be filling. Assuming Denver Water's reservoirs fill sufficiently, the borrowed water could be used by the South Metro water providers without payback of water to Denver Water.

Because wet years cannot be predicted with certainty, however, there would be years where this water "borrowing" would result in draw-downs to Denver Water's reservoirs that would not refill from late spring runoff. In these cases, the borrowed water would have to be paid back to Denver Water. While the water would need to be paid back in the same year, the payback could potentially be delayed until the fall and winter. Payback water would be the same water that was "borrowed" and stored in new South Metro storage reservoirs.

Denver Water's surface water model, PACSM, was used to simulate the delivery of surface water to Douglas County in Alternative 3A. In this model, the water rights used for Douglas County's benefit were assumed junior to those of Denver Water and other major metropolitan water supply systems (e.g. Aurora, Thornton, Englewood, etc.), as well as those of Grand and Summit Counties. This means that this new water right would not impact any other entities' water rights on these rivers.

Alternative 3A assumes 39,000 acre-feet of new reservoir storage would be developed in the South Metro Area to store water borrowed from Denver Water. Also, new raw water pipelines, pumping stations and water treatment facilities would be constructed so that treated water could be distributed to the individual water providers' systems.

Alternative 3B - Conjunctive Use with Free River Water.

Alternative 3B is very similar to Alternative 3A except that water from the upper South Platte and Blue River is diverted directly without using existing Denver Water storage facilities.

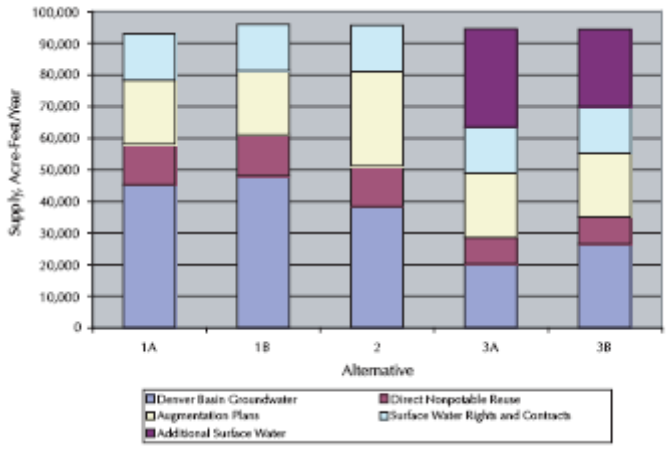
Under this "free river only" scenario, water would be diverted from the South Platte and/or Blue River and would be transported to the South Metro area in the same manner as in Alternative 3A. Normally water would only be available for diversion during periods of relatively high river flows, typically in May and June. Under Alternative 3B, diverted water could be used to directly meet the water demands of Douglas County providers, stored in surface reservoirs, or used to recharge the Denver Basin Aquifers. In general, the infrastructure required in Alternative 3B is the same as Alternative 3A.

Key Findings

Water Supply Comparisons for 2050

The water management model was run for each alternative. The model created a water supply management plan for the individual water providers and for the study area as a whole. The results of the modeling for the area as a whole in 2050 are presented for each alternative in Figure 2 below. These results show the volume of water to be used from each available water supply source. Of particular interest is the volume of ground water pumping required.

Figure 2
Comparison of 2050 Results



The chart above illustrates that the annual volume of ground water pumped is highest in Alternatives 1A and 1B and decreases substantially in Alternatives 2, 3A and 3B. In Alternative 2,

the reduction in ground water use is due to increased reuse of approximately 9,400 acre-feet. This is the maximum amount of reuse that can be achieved. Realistically, it will be less than this projection.

In Alternative 3A, the reduced ground water pumping is due to gross water deliveries from the South Platte and Blue River that would average about 36,000 acre-feet per year, with payback to Denver Water averaging about 10,000 acre-feet per year. Thus, this "free river with borrowing" scenario would produce an average net yield (deliveries minus payback) of approximately 26,000 acre-feet per year. Of this amount, approximately 15,000 acre-feet per year would come from the Blue River and approximately 11,000 acre-feet per year would come from the South Platte River. However, there would be extended dry periods (four years or longer) when there would be little or no surface water available from the South Platte or Blue River under this scenario.

In comparison, Alternative 3B, the free river only scenario, would reduce ground water pumping by producing an average net yield of approximately 19,000 acre-feet per year from the South Platte and Blue River, with about half coming from each. There would be no payback to Denver Water in this scenario.

These results show that ground water pumping can be greatly reduced under Alternatives 2, 3A, and 3B. However, the reduced levels of ground water pumping under Alternative 2 are probably unrealistic due to overly optimistic maximum reuse projections.

Aquifer Water Levels and Pumping Rates Over the Study Period

An important goal in evaluating the Denver Basin Aquifers as a source of water supply for the South Metro area was to understand the viability of the supply on a long term basis. The study found that the key issue today is not the draining of the resource, but instead exceeding the reasonable and prudent production capability of the aquifer system.

The study shows that in urbanized areas, even though the volume of appropriated water may be sufficient to meet demands, the water supply cannot be produced at the appropriated volume without large drawdowns in the aquifer water levels. In the future, these large drawdowns will reduce well production drastically and make production difficult and costly.

Even with expanded conservation and reuse by water providers, the study found that the projected pumping volume will dissipate the artesian pressure from the Denver Basin Aquifers to a large extent over the next 10 to 20 years. This artesian pressure has greatly aided well production in the past since the ability to pump water is directly proportional to pressure. While the water associated with the artesian pressure is a small percentage of the total water volume in the aquifer, the loss in artesian pressure represents a large percentage of the pressure available to obtain water from the aquifers. As such, the problem with continued pumping of the Denver Basin Aquifers is much more related to a significant drop in the rate of well production (the gallons per minute of withdrawal) as opposed to the diminishment of total water stored in the aquifers.

The results of the local well analysis also indicate that the lowering of regional ground water levels is severely compounded by the well-to-well interference that will occur if these aquifers are pumped at the projected rates. The analysis found well-to-well interference can further lower pumping water levels by more than 100 feet.

As regional water levels drop to near the top of the aquifer, the additional drop in ground water levels caused by well-to-well interference will result in a dramatic loss in well production. In 2003, the maximum Arapahoe aquifer pumping rates in the South Metro Area generally ranged from 500 to 600 gpm. The study found that in Alternative 1A the pumping rate will drop in a typical well to 300 gpm by 2010, and to 80 gpm by 2050. The resulting loss in production is somewhat less for other aquifers, however, other aquifers start with much lower production rates than the Arapahoe Aquifer.

Of particular significance is that by the year 2050, a well producing a maximum of 100 gpm in any aquifer will be considered successful in terms of production. But wells producing only 100 gpm are extremely uneconomical and the cost for the number of wells required to meet demand in that scenario will be considerable.

Table 3 shows the total number of additional wells required by alternative and aquifer to meet demands by 2050. Well construction and infrastructure is very costly and these wells represent huge increases in required capital facilities costs.

Table 3
Total Number of Additional Wells By Alternative & Aquifer

Alternative 1A	57	210	954	143	1364
Alternative 1B	32	180	373	75	660
Alternative 2	28	173	115	65	381
Alternative 3A	30	38	146	84	298
Alternative 3B	30	69	140	78	317

Conclusions

The findings of this study indicate that continued reliance on the deep ground water aquifers to meet urban demands in the South Metro Area will result in very large increases in capital and production costs in the foreseeable future, and perhaps the eventual loss of ground water as an economically viable resource.

The study highlights the fact that expected declines in artesian pressure and ground water levels will seriously impact the provider's ability to efficiently produce deep ground water supplies. In every alternative, the artesian pressure will be depleted or reduced to a minimum over the next 20 years, thereby requiring ever-increasing numbers of additional wells to produce the same volume of water. The results of the infrastructure costing analysis show that ground water pumping to meet future demand will be extremely costly. Therefore, any effort to reduce ground water pumping will result in significant cost savings.

The bottom line: From a water management perspective, this study indicates that the South Metro Denver region could drastically reduce its future level of reliance on Denver Basin ground water by vigorously pursuing a combination of water conservation, augmentation and reuse, surface water development, storage, and aquifer recharge initiatives.

Alternative 1A (Status Quo) – This alternative, which relies most on increased ground water pumping, becomes increasingly expensive in the foreseeable future and may be economically unsustainable in the long-term.

Alternative 1B (Status Quo with Storage for Peaking) – This alternative reveals that reducing the number of wells saves significantly more than the cost increase associated with the construction of water storage and treatment.

Alternative 2 (Non-Tributary Ground Water with Maximum Reuse) – The reuse strategies in Alternative 2 should be fully pursued since, in all cases, the cost of developing reuse is less expensive than further development of ground water. To the extent this reuse can be achieved, this alternative becomes an enhancement to Alternatives 1B, 3A and 3B.

Alternative 3A (Conjunctive Use with Borrowing from Denver Water Storage) – This alternative results in surface water import of an average of 26,000 acre-feet per year during the study period, which amounts to about 1.1 million acre-feet less ground water usage than Alternative 1B over the study period.

Alternative 3A is estimated to cost about $300 million more than Alternative 1B including capital, operation and maintenance, and repair/rehabilitation costs.

Alternative 3B (Conjunctive Use with Free River Water) – This alternative is actually less expensive than Alternative 1B when considering all costs. It creates less new surface water yield than 3A, averaging 19,000 acre-feet per year, but the 19,000 acre-feet is gained with about the same capital cost and less total cost than any of the groundwater alternatives. This is because the savings achieved through reduced well pumping almost equals the cost of the infrastructure neccessary to import renewable water and operating costs are considerably less. This plan also avoids the need for a payback scenario to Denver Water and avoids environmental concerns associated with reduced water levels in Dillon and Cheesman Reservoirs.

3A and 3B Additional Cost Considerations – It is important to note two significant considerations in reviewing costs for Alternatives 3A and 3B:

First, Alternative 3A assumes the use of Denver's raw water storage and treatment facilities, and both Alternatives 3A and 3B assume the use of Denver Water's delivery systems to capture and convey flows to the South Metro area. Denver Water has not yet agreed to allow the use of these facilities. If Denver Water were to cooperate in such a plan, they would need to be compensated appropriately for the use of these facilities. While estimated compensation costs to Denver Water are included in these alternatives, at this point the exact compensation and the means of compensation have yet to be determined.

Second, Alternatives 3A and 3B assume additional surface water depletions from the Blue River and the South Platte River. Additional depletions will need to be mitigated, and the cost of mitigation is expected to be substantial. Therefore, the costs for Alternatives 3A and 3B are not complete, and are likely to be significantly higher than presented herein.

The conjunctive use alternatives present a prudent approach to water development. These plans include expanded conservation, high percentages of reuse, and a component of ground water production. The plans conjunctively use surface water and ground water to create a better balance of water supplies -- relying more on surface water in wet years and more on ground water in dry years.

Recommendations

Implement the measures aimed at reducing the volume and the rate of ground water withdrawals, including expanded conservation, maximum reuse, and the import of renewable surface water through a conjunctive use plan. This study indicates the cost of water conservation and water reuse in almost any form is economically beneficial to the South Metro water providers, individually and collectively.

Seek further information from Denver Water and the Colorado River Water Conservation District related to Alternative 3B. The eventual costs of Alternative 3B would include actual charges Denver Water might impose for use of its facilities, mitigation for West Slope impacts and other costs. These costs will need to be added to the currently identified costs for Alternative 3B, before this alternative can be truly compared to the 1B groundwater alternative. However, by 2050, Alternative 3B would reduce the draw on the aquifer system by an estimated 1 million acre-feet and provide an average of 19,000 acre-feet annually of renewable water yield to the South Metro Area. In addition, reuse opportunities could almost double the actual value of supply realized through the importation of this water. Further analysis of this alternative should seek to increase this yield since it would be fairly small for a project of this magnitude.

The other significant benefit of Alternative 3B is that the project could be phased in and partially implemented with minimal initial infrastructure. The water storage and delivery systems of Denver Water are already in place and deliveries of excess water in wet years could be made to a number of participating water providers. Centennial and Inverness already have connections to Denver Water that would allow for delivery of some water under this plan. In addition, with a very short pipeline connection, Denver Water could connect with East Cherry Creek Valley's existing pipeline along C-470 near Quebec Street, enabling water deliveries to ECCV, Meridian, Stonegate and Cottonwood through this pipeline.

However, before this phasing could occur, Denver Water and the Colorado River Water Conservation District have defined a need for a single entity from the South Metro Area to negotiate and implement a potential project. In addition, Denver Water has given no indication that it is amenable to phased implementation.

Alternative 3A should not be entirely eliminated from further consideration at this point. Instead, this plan should continue to be considered as further information is developed with Denver Water and the Colorado River Water Conservation District as part of these potential conjunctive use plans. Alternative 3A provides an additional 7,000 acre-feet of average annual water delivery beyond the 19,000 acre-feet of Alternative 3B. This additional yield would be very important to the South Metro Area.

Additional reuse strategies contained in Alternative 2 should be fully pursued and implemented where these additional reuse opportunities are deemed achievable. This additional reuse would reduce the total cost of water supply

and further maintain the viability of the ground water through an additional reduction in ground water withdrawals.

The decision to pursue a course of action must be made by the water providers as a unified group. The Boards of Directors of each District and the Town Council of Castle Rock will need to decide if they are willing to pursue a conjunctive use plan. These decision-makers also will need to consider a large near-term increase in tap and service fees necessary to fund any of these alternatives.

If the water providers as a group decide to pursue Alternative 3A or 3B, then discussions can be initiated with Denver Water to determine costs, appropriate compensation and other requirements regarding this alternative. At the same time, deliberations could begin with the Colorado River Water Conservation District regarding a study that would identify the impact of stream depletions and consider various mitigation plans that would properly compensate the area for additional surface water diversions.

Appendix D
Ecosystem Restoration Evaluation Report

Draft for Discussion Purposes Only

Revised Draft Ecosystem Restoration Evaluation Report

Chatfield Reservoir Reallocation Study

February 4, 2008

Prepared by:
Great Western Institute
Miller Ecological Consultants, Inc.
Denver Water

Draft for Discussion Purposes Only

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Attachments

- A - Habitat Suitability Data for Species of Interest
- B - Cross Section Flow and Wetted Perimeter Analysis
- C - Habitat Flow Relationships
- D – Summary of Wet and Average Year Habitat Area Change for Fish Species of Interest

Section 1
Introduction

The South Platte River corridor provides important natural resources and associated aesthetic and recreational opportunities to millions of people living along its banks in the Colorado Front Range. The river serves to transport water from the mountains down to the thirsty municipal and agricultural water users lining the foothills, stretching out into the state's eastern plains. Along the way, the river's natural ecosystem contains a great diversity of flora and fauna that rely upon the river for food and habitat. The river also provides for numerous, important recreational opportunities, which help to support the local economy.

On its route from the mountains to the eastern plains, the South Platte River passes through the Denver metropolitan area. The river is challenged to maintain its ecological and environmental functions as the urban setting increasingly encroaches on its banks and impacts the water's flow and quality. Upstream reservoirs, channelization, wastewater discharges, and diversions all influence the aquatic habitat quality and riparian corridor. In addition, river flows are at times not sustainable such that in some locations the river is dry and/or discontinuous during various times of the year, especially during the winter months.

A once-in-a-generation opportunity to improve flows below the Chatfield Reservoir is within reach – which involves the retiming of South Platte River runoff by reallocating storage in Chatfield Reservoir. In 1986, the federal government authorized the US Army Corps of Engineers (USACE) to evaluate the:

> ",…feasibility and economic justification to reassign a portion of of the storage space in the Chatfield Lake project to joint flood control-conservation purposes, including storage for municipal and industrial water supply, agricultural, and recreation and fishery habitat protection and enhancement." (excerpt from Section 808, Water Resources Development Act (WRDA) 1986)

Therefore, through appropriate planning and implementation, water may be placed in the South Platte River at times when it is most needed to help enhance and protect fishery (and other water dependent species) habitat, in conjunction with and without compromising other programmed water uses (e.g., municipal and industrial water supply, etc.).

Study Objectives

The study described and discussed in this white paper was developed to evaluate the opportunities to protect and enhance fishery habitat below Chatfield Reservoir through the management of future water releases from the reallocated storage conservation pool, which for purposes of this white paper was assumed to be 20,600

acre-feet extending for 12 feet above the current Denver Water 27,428 acre-foot pool. Note that improving the fishery habitat is also expected to improve the general river ecosystem and recreational opportunities within and adjacent to the river.

Note that this study is based on analyses conducted in the third and fourth quarter 2006, as well as supplemental analyses conducted in the past three months, from November 2007 to January 2008. The combined set of hydrologic and biologic analyses provided herein are considered to be limited to a set of preliminary options associated with the management of future reservoir releases from the reallocated storage managed for water supply, recreation and fishery habitat protection and enhancement. Additional analyses may be needed to expand the understanding of the benefits of managed releases on the downstream fishery and aquatic habitat – either during the development of the USACE Feasibility Report (as a means to establish a credit for the capital cost of storage), preliminary design of the environmental and recreational mitigation efforts (as a means to reduce mitigation costs and/or receive dispensation from the USACE for ER benefits), or future reservoir operations.

Study Sponsors

The work presented in this white paper was performed as a result of funding provided by the downstream and selected upstream water users associated with the Chatfield Reallocation project including: City of Aurora, the City of Brighton, Castle Pines Metro District, Castle Pines North Metro District, Central Colorado Water Conservancy District, and Western Mutual Ditch Company; as well as the instream users: City and County of Denver, Denver Water (DW), the Greenway Foundation, the City of Littleton, and the Metropolitan Wastewater Reclamation District (Metro).

Section 2
Approach and Methodologies

Overview

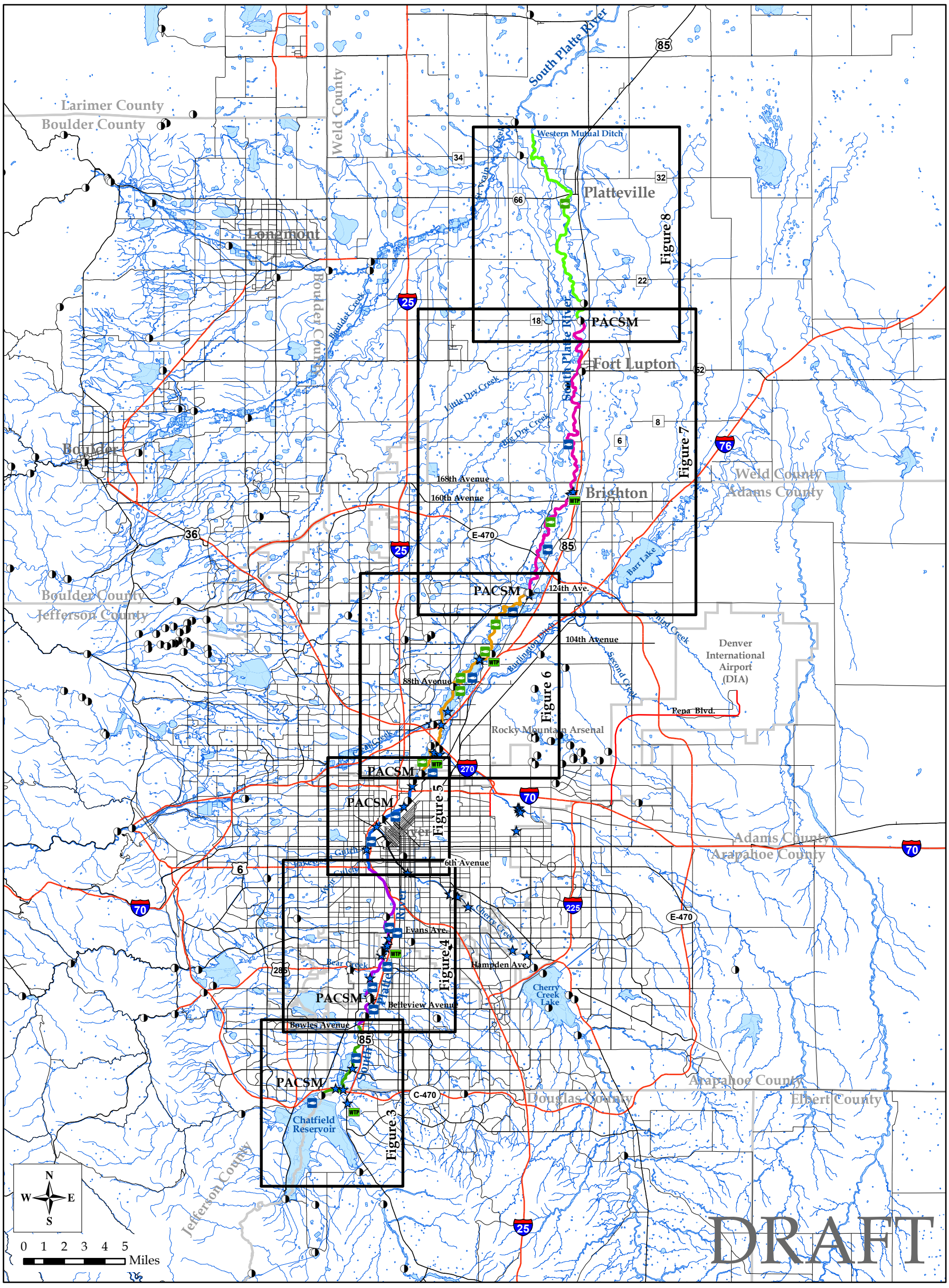
Technical analyses were performed to characterize the benefit of having retimed flow in the South Platte below Chatfield Reservoir associated with the reallocation of flood storage in Chatfield. Specifically, the analyses involve coupling hydrologic and hydraulic calculations with characteristic habitat suitability information to estimate changes to habitat quantity for selected fish – both juvenile and adult – based on various future river flow regimes for conditions with and without the Chatfield storage reallocation.

The study area was established based on the location of available river cross-sectional information, river gages, and the diversions of downstream water users. Figure 1 presents the overall study area.

The specific flow regimes that were evaluated during this study include two sets of "baseline hydrologic conditions" – including the current configuration of the hydrologic setting (aka 2005 conditions) and the hydrologic setting representing expected build-out of the Chatfield Reservoir system (aka 2050). These two baseline conditions were developed assuming that reallocation of Chatfield storage does not occur now or into the future.

Using these two baseline conditions, two scenarios were developed to simulate future releases from Chatfield assuming that reallocation will occur – the first, based on water user defined releases from both upstream and downstream water users; and the second, based on water user defined releases for the upstream water users only. For this second scenario, it was assumed that the downstream water users would release water only at times when flows at locations downstream of Chatfield fell below 10 cubic feet per second (cfs). The second scenario allowed for reservoir releases whenever downstream flows were less than 10 cfs at any time, as long as water remained in the reallocated storage pool, thus representing a more ecosystem restoration (ER) friendly future water release scenario than the pure water user defined releases used for the first scenario. This second release scenario was compared to the first release scenario to gain insight into how alternative water release schemes could improve the downstream fishery habitat without substantially compromising downstream water supply needs. This study assumes that the downstream water users have complete flexibility in releasing water they have stored in the reallocated Chatfield storage pool.

Physical Habitat Simulation System (PHABSIM) analyses were performed to combine channel hydraulics with habitat use information provided by various sources and approved for use in this study by the Colorado Department of Wildlife



Legend

- USGS Gage
- Water Quality Sampling Location
- Wastewater Treatment Plant
- 2005 South Platte CURE Study
- 1993 Metro Study HSI (5 Station Locations)
- Lakes
- Rivers
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- Burlington Ditch to Henderson Gage
- Henderson Gage to Fort Lupton Gage
- Fort Lupton Gage to Western Mutual Ditch

Figure 1 - Ecosystem Restoration Study Area

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(DOW) to predict habitat quantity for a range of flows. Using the above alternative flow scenarios, the habitat discharge relationships were combined with flow to produce a quantification of habitat over time.

Specific assumptions and methodologies used for each of the modeling efforts used to analyze the different water release scenarios are discussed in the sections below.

Methodology

Hydrology – DW provided information on baseline hydrology in the South Platte River, as well as information on the frequency and duration of future releases from Chatfield Reservoir to the South Platte based on criteria developed by the Technical Working Group in 2006. Specifically, DW used output data from its proprietary PACSM model in a spreadsheet model (described in more detail below) to estimate daily flows at six locations in the river downstream of Chatfield:

- Chatfield Outflow
- Englewood Gage at Union Boulevard
- Denver Gage at 19th Street
- Below Burlington Canal above 58th Street
- Henderson Gage at 120th Street
- Fort Lupton Gage

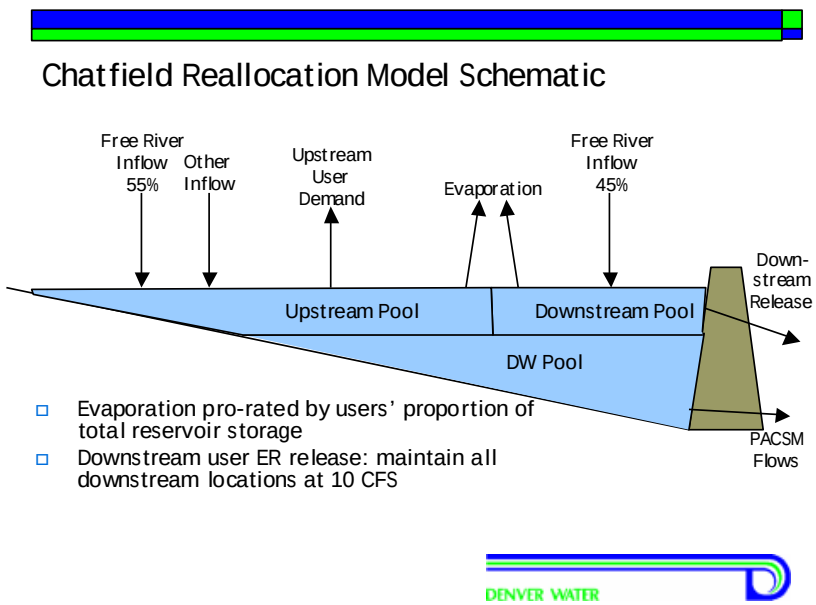
PACSM is a complex river system model developed and used to determine DW's water supply in the South Platte and Colorado River systems. The model incorporates the water systems and water rights of DW and others at over 450 nodes.

PACSM has been reviewed and accepted for use as a water allocation model by numerous experts. It has been reviewed by the USACE for its use in the Moffat EIS. It has also been reviewed by FERC for two re-licensing efforts. Numerous local water providers and consultants have also reviewed it in conjunction with various east and west slope water studies.

Under the two development conditions used for this study – 2005 and 2050 – daily hydrology for the period from 1947 through 1991 was input to PACSM to simulate expected flows at the six stations indicated above (as shown on Figure 1 and Figures 3 through 8) for the situation where the pool elevation does not rise above an elevation of 5,432 feet, which is the top of DW's 27,428 acre-foot pool. Operating Chatfield in this manner was considered the "baseline" condition against which the impact of future releases from the reallocated storage on downstream fishery habitat was compared.

To simulate downstream releases from the reallocated storage pool, which exists above DW's pool extending from elevation 5,432 to 5,444 feet, PACSM output data was used in a spreadsheet model, which tracked free river inflows, other inflows, upstream water user demand, evaporation and either downstream water user demand or downstream water user releases to maintain 10 cfs in selected reaches. To this end, three simulated flows were developed at each of the six downstream stations for two different baseline conditions. These alternative flow scenarios are summarized in Table 1. A schematic of the spreadsheet conceptual model is provided in Figure 2.

Figure 2



DW's current Chatfield pool operation was represented by storage data from the PACSM model. The reallocation pool was simulated on a daily time step above Denver Water's pool. For reservoir inflows, the spreadsheet model used inflows available from a new (junior) water storage rights and inflows from other upstream sources to fill the reallocation pool.

Table 1 - Summary of Hydrologic Simulations

PACSM Run	Spreadsheet Run	Reservoir Outflow Conditions
Baseline – 2005 Conditions	None	Existing
	Reallocation without ER	Upstream and Downstream User Specified
	Reallocation with ER	Upstream User Specified, Downstream based on river need for 10 cfs
Baseline – 2050 Conditions	None	Existing
	Reallocation without ER	Upstream and Downstream User Specified
	Reallocation with ER	Upstream User Specified, Downstream based on river need for 10 cfs

The spreadsheet model also calculated the releases from the reallocation pool to the South Platte River based on the water available in the reallocation pool. To this point, the spreadsheet model calculated releases based on the alternative downstream flow conditions – either those specifications defined in the EIS by the downstream users or those defined by minimum flow requirements (i.e., the 10 cfs preliminary ER release). The resultant changes in outflows from the baseline conditions were added to, or subtracted from, downstream flows calculated by

PACSM at the six downstream gage locations. Upstream users' outflows were withdrawn directly from Chatfield or its outlet works and did not affect downstream flows, but were nonetheless tracked in the model.

Evaporation from the Chatfield reallocation pool was assumed to equal a pro-rated share of the calculated evaporation based on the water user's portion of the total reservoir storage. The spreadsheet model did not simulate individual water user pools or inflows or outflows, but rather lumped upstream users together and downstream users together. The spreadsheet model did not account for unused inflow, nor did it include carriage losses on water released to the river.

Quantitative Biology - The quantitative methodology, as approved by the Technical Working Group, was based upon the linkage of the hydrology with PHABSIM which characterizes changes in stream flow velocity, depth, wetted perimeter, as well as other physical habitat information, for purposes of estimating habitat area for each of the alternative flow scenarios for the South Platte from Chatfield downstream to below Fort Lupton.

PHABSIM was developed using the following data:

<u>Cross-Sections and transects and other related hydraulic data</u>

- The City of Littleton provided 6 cross sections located in South Platte Park to characterize the reach from Chatfield downstream to Englewood;
- The DW provided 11 cross-sections based on from past Two-Forks efforts for locations near Union Street, Evans and Franklin Street; and
- Metro provided 5 cross sections from Burlington Ditch downstream to Fort Lupton.

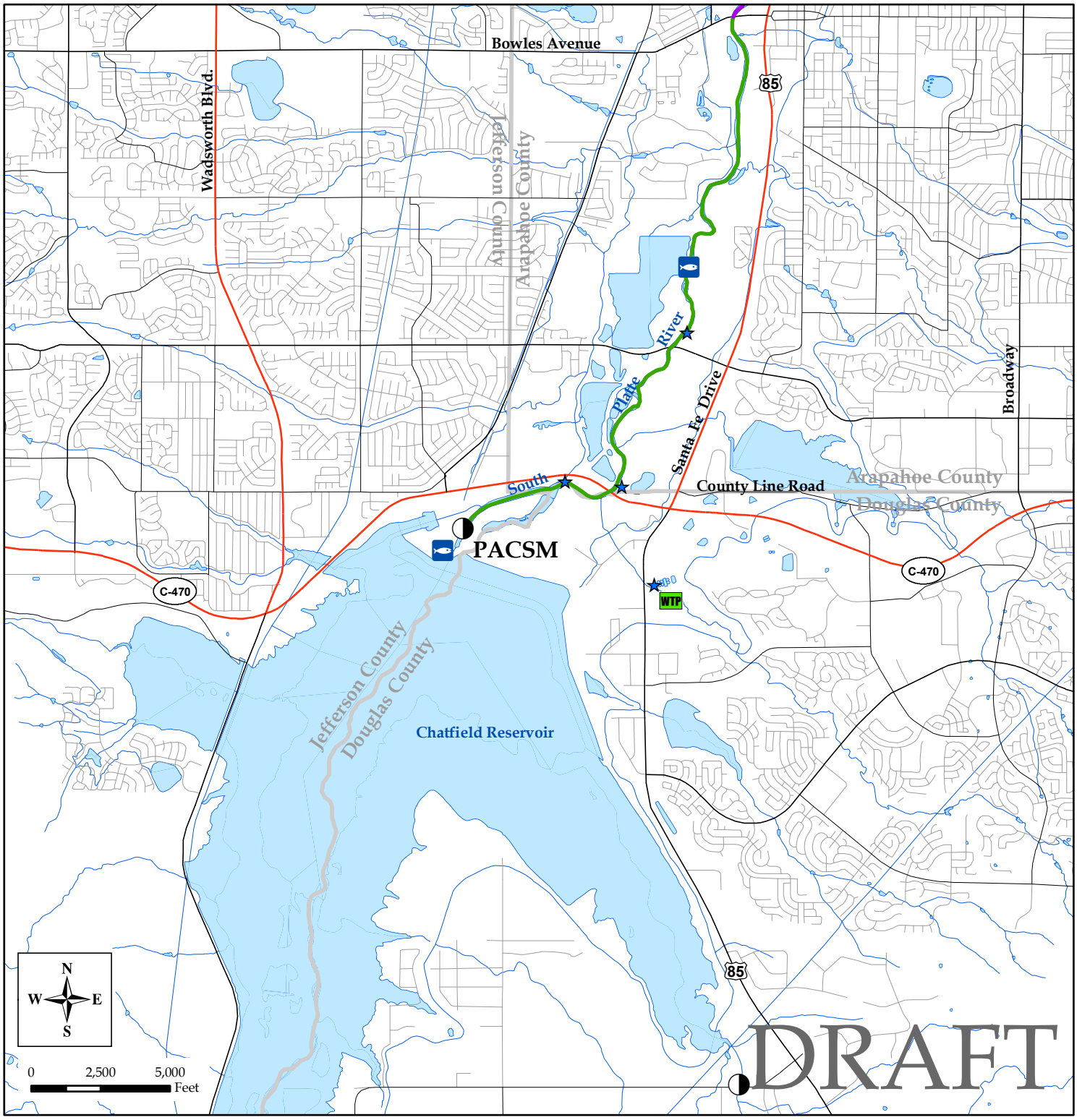
Figures 3 through 8 present the location of each of these reaches of interest and the associated cross sectional information relative to the hydrologic stations.

<u>Location of pools, riffles and glides</u>

The sections provided by Littleton, DW and Metro include characteristic riffles and run within each of the six reaches. Specific information regarding the size and location of the river bed features was developed based on past modeling efforts and recent and past field reconnaissance by Chadwick Ecological Consultants and Miller Ecological Consultants for South Platte CURE, Metro, and other studies in the river.

<u>Habitat suitability data</u>

Habitat suitability data, which was used to develop the flow versus habitat relationships, is contained in Attachment A. These data were based upon DOW approved and/or reviewed studies as follows:



Legend

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- Bowles Avenue to 6th Avenue
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- Burlington Ditch to Henderson Gage
- Henderson Gage to Fort Lupton Gage
- Fort Lupton Gage to Western Mutual Ditch

Figure 3 - Chatfield Reservoir to Bowles Avenue Reach

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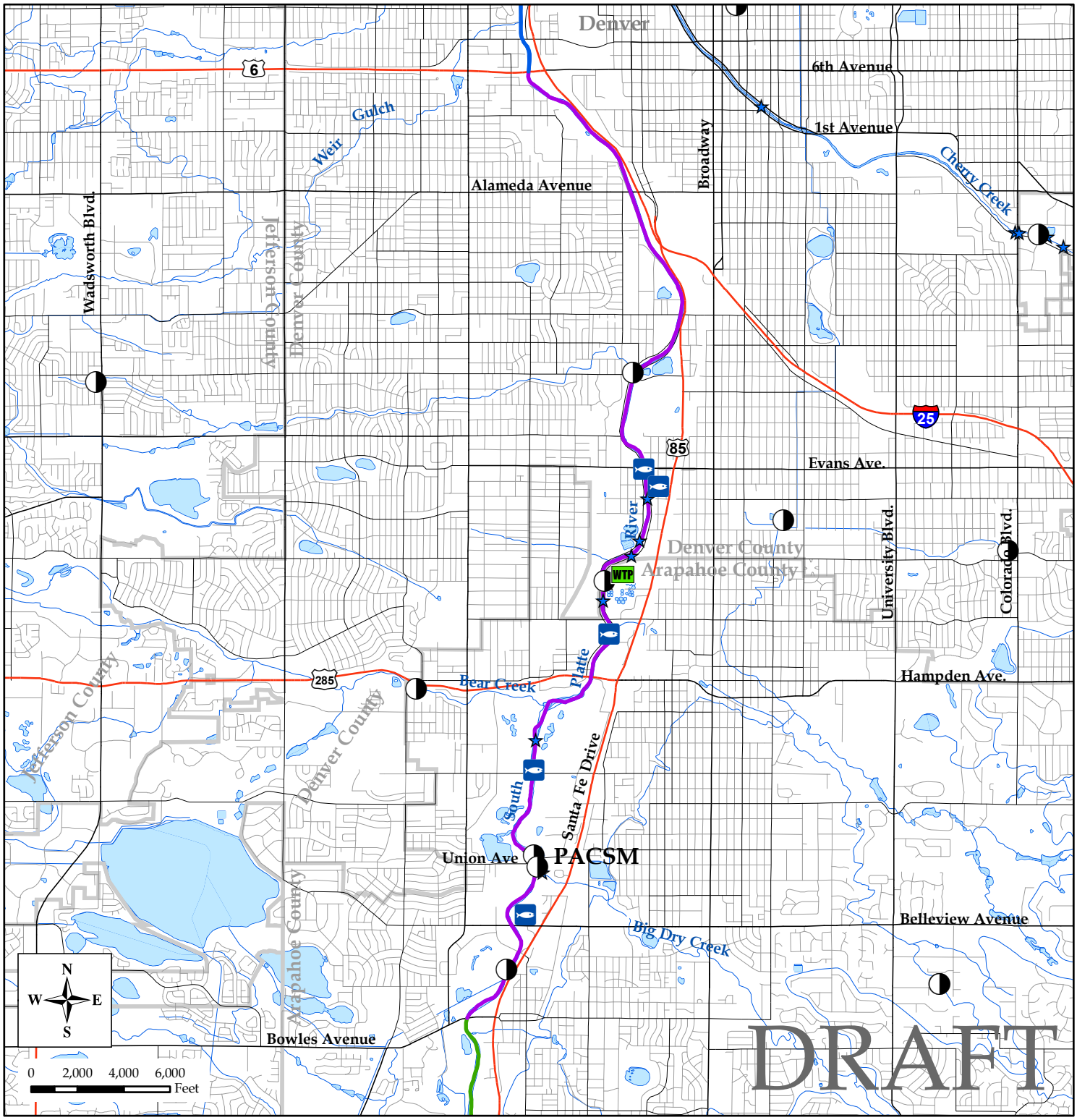

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Figure 4 - Bowles Avenue to 6th Avenue Reach

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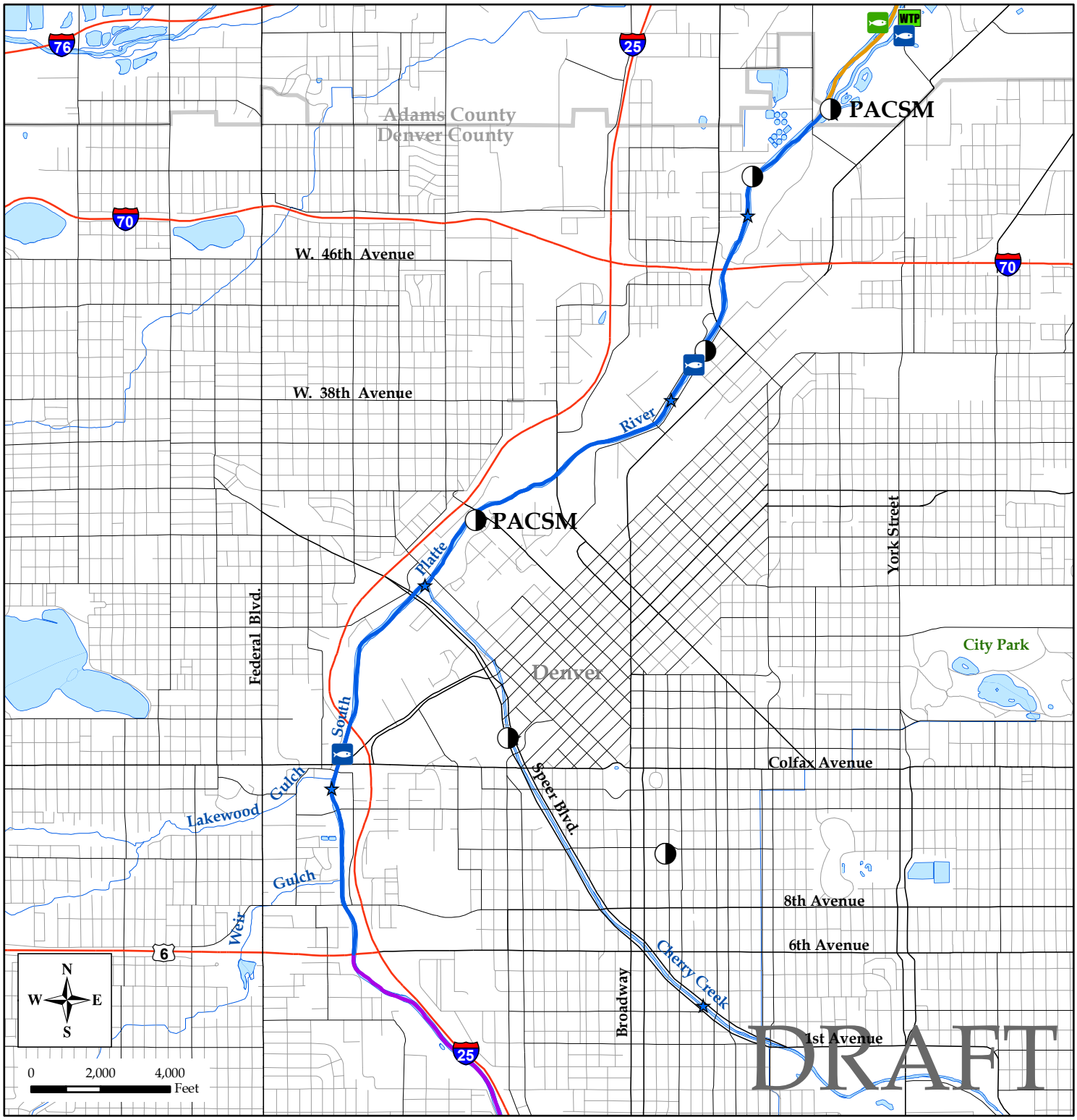

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- Fort Lupton Gage to Western Mutual Ditch

Figure 5 - 6th Avenue to Burlington Ditch Reach

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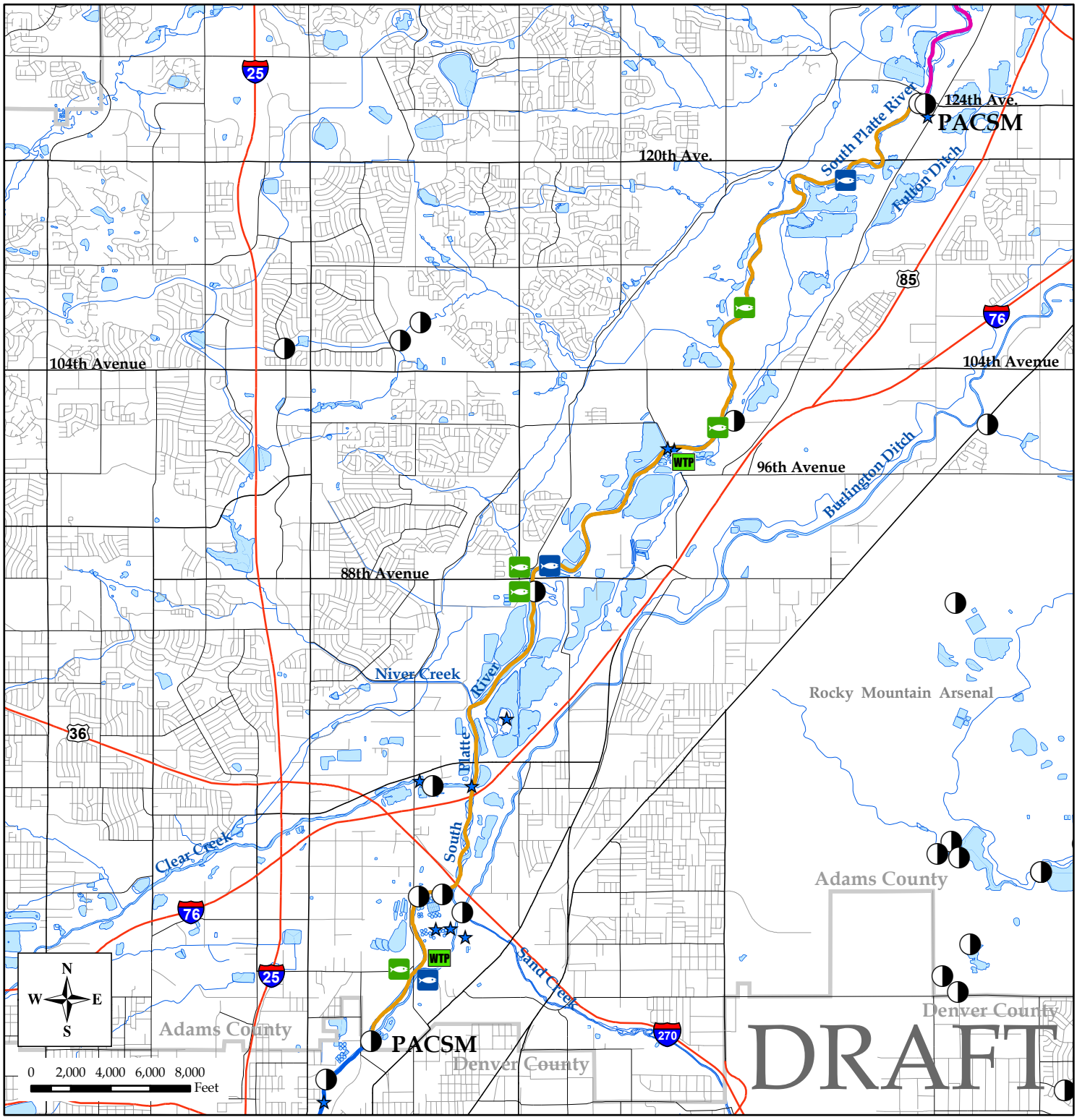

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- Henderson Gage to Fort Lupton Gage
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Figure 6 - Burlington Ditch to Henderson Gage Reach

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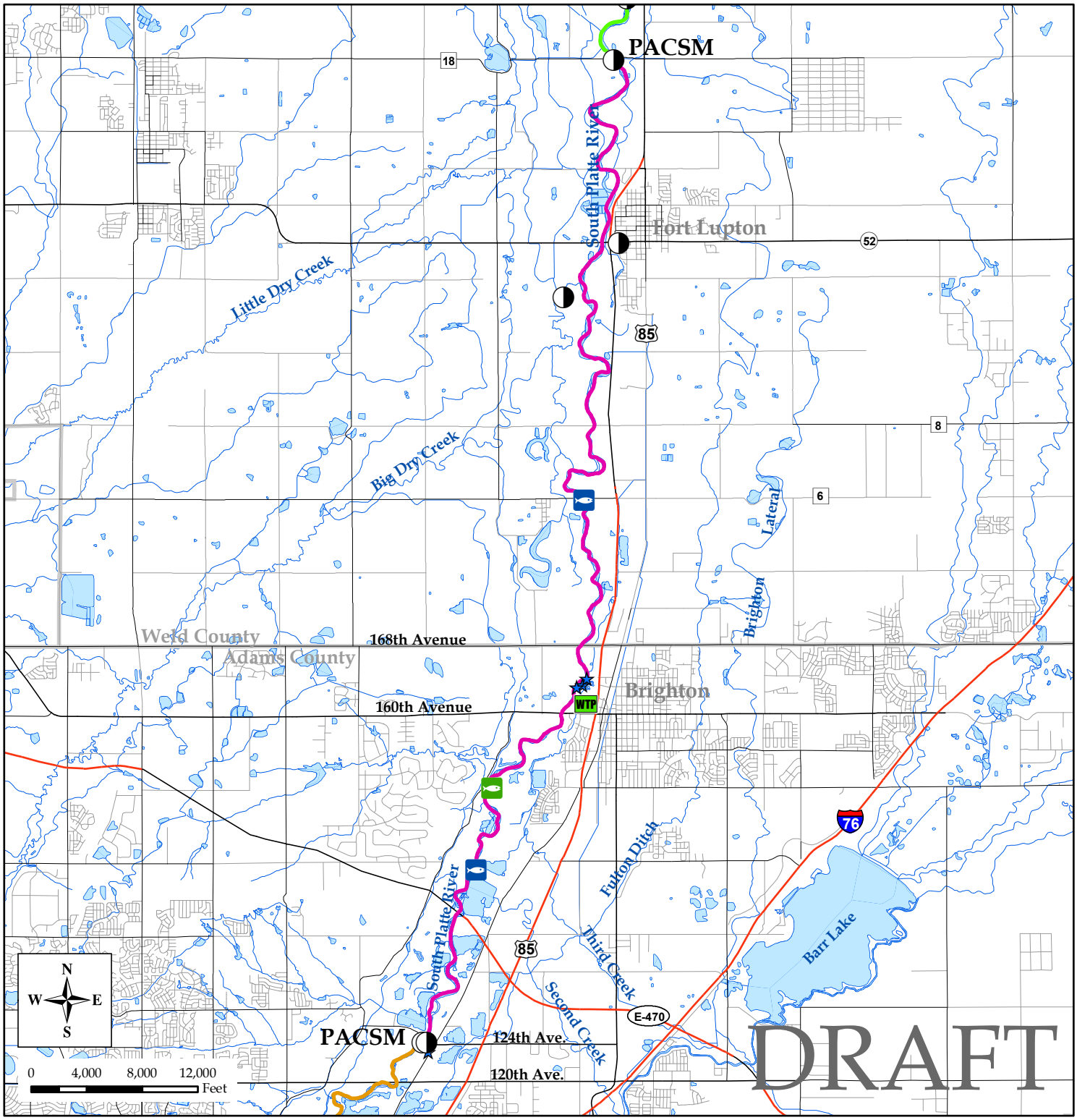

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- Burlington Ditch to Henderson Gage
- Henderson Gage to Fort Lupton Gage
- Fort Lupton Gage to Western Mutual Ditch

Figure 7 - Henderson Gage to Fort Lupton Gage Reach

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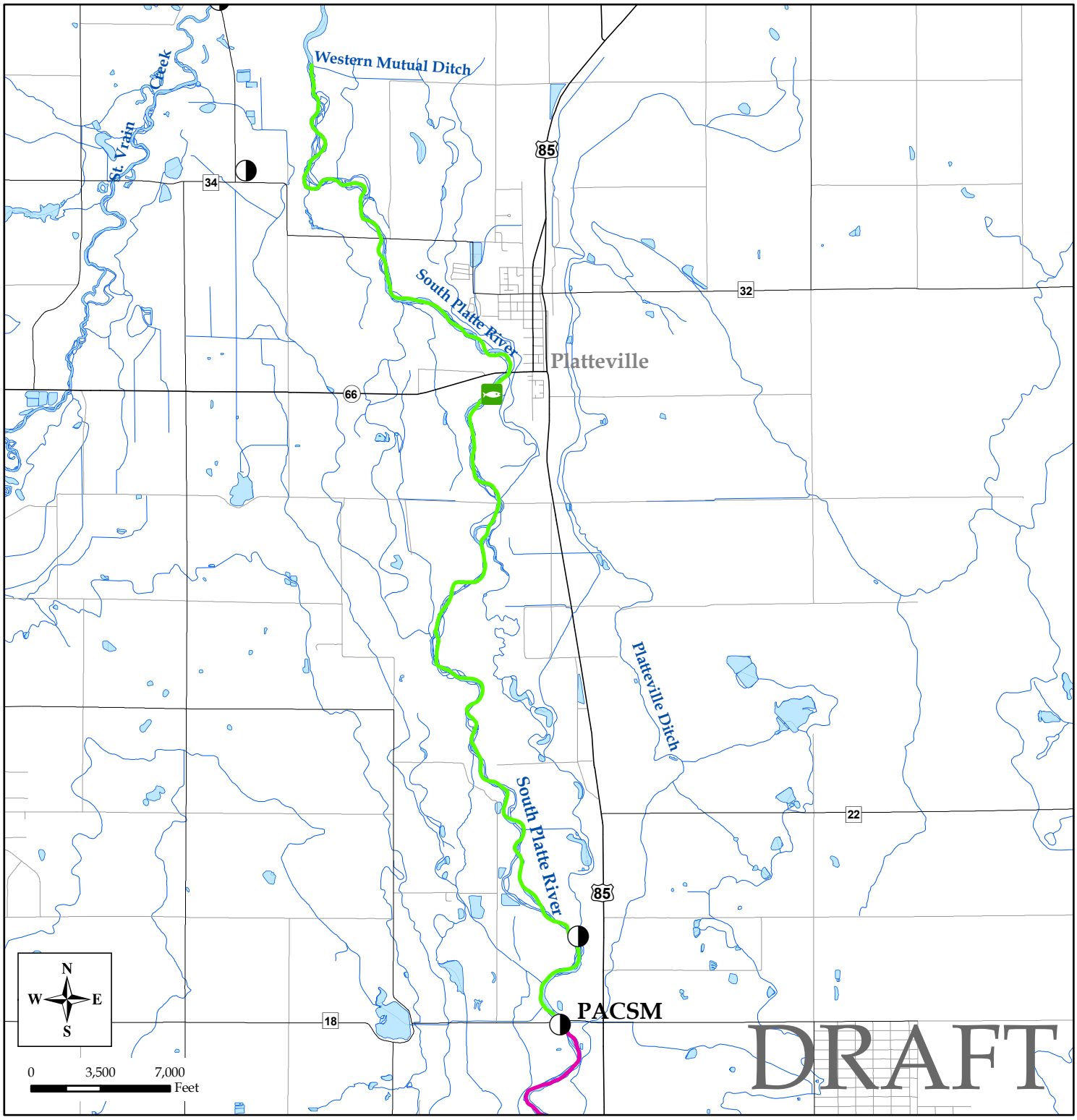

Figure 8 - Fort Lupton Gage to Western Mutual Ditch Reach

Legend

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- Wastewater Treatment Plant
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- Brown and rainbow trout, juvenile and adult - CDOW South Platte River
- Channel catfish, adult – Peters et al. 1989 – Platte River
- Channel catfish, juvenile – Chadwick Platte River
- Common carp, adult - Chadwick Platte River
- Sand shiner, adult - Chadwick Platte River
- Longnose dace, adult – USFWS HSI criteria
- White sucker, adult and juvenile - USFWS HSI criteria

Some of these data may need some "tweaking" in the future depending on the use of the habitat assessment; however DOW is comfortable using this combination of literature for this application since they have been successfully applied to the South Platte in the past. Future adjustments may, nonetheless, be needed to account for the unique combination of warm and cool water environments in the South Platte River below Chatfield Reservoir.

PHABSIM and habitat time series analyses were used to develop habitat unit duration and exceedance curves for the alternative flow scenario impacts on fisheries in the South Platte River. Specifically, the biological modeling proceeded as follows:

- Depth, wetted perimeter, and velocity were estimated over the range of expected flows included within each alternative to characterize habitat within each cross section for each species and fish type (i.e., juvenile and adult);
- Habitat versus flow relationships were developed for each reach and fish type and species over the range of expected flows using the habitat suitability data;
- Simulated daily flows for each alternative hydrologic condition were developed using modeling data for the period from 1947 to 1991 and converted to habitat area in each reach based on the habitat versus flow relationships developed in the last step; and
- Habitat area was evaluated against return period (i.e., habitat vs. time) across the entire reach from Chatfield to Fort Lupton to characterize the benefits of the proposed storage reallocation, and to determine whether or not "ER Releases" would provide additional benefits to the fisheries above and beyond those that are expected to occur when and if the reallocation occurs.

A supplemental analysis was also performed using the hydrology developed by DW. Specifically, PHABSIM was used to characterize the habitat area benefits of retimed releases for wet and average flow years on the river under the various future release scenarios (i.e., Chatfield with and without the ER release for both current and built-out conditions). Note that no supplemental analyses were performed for dry flow year, since there will not be any retimed releases from

Chatfield in dry conditions and therefore there are no incremental benefits during periods of time when no releases can occur.

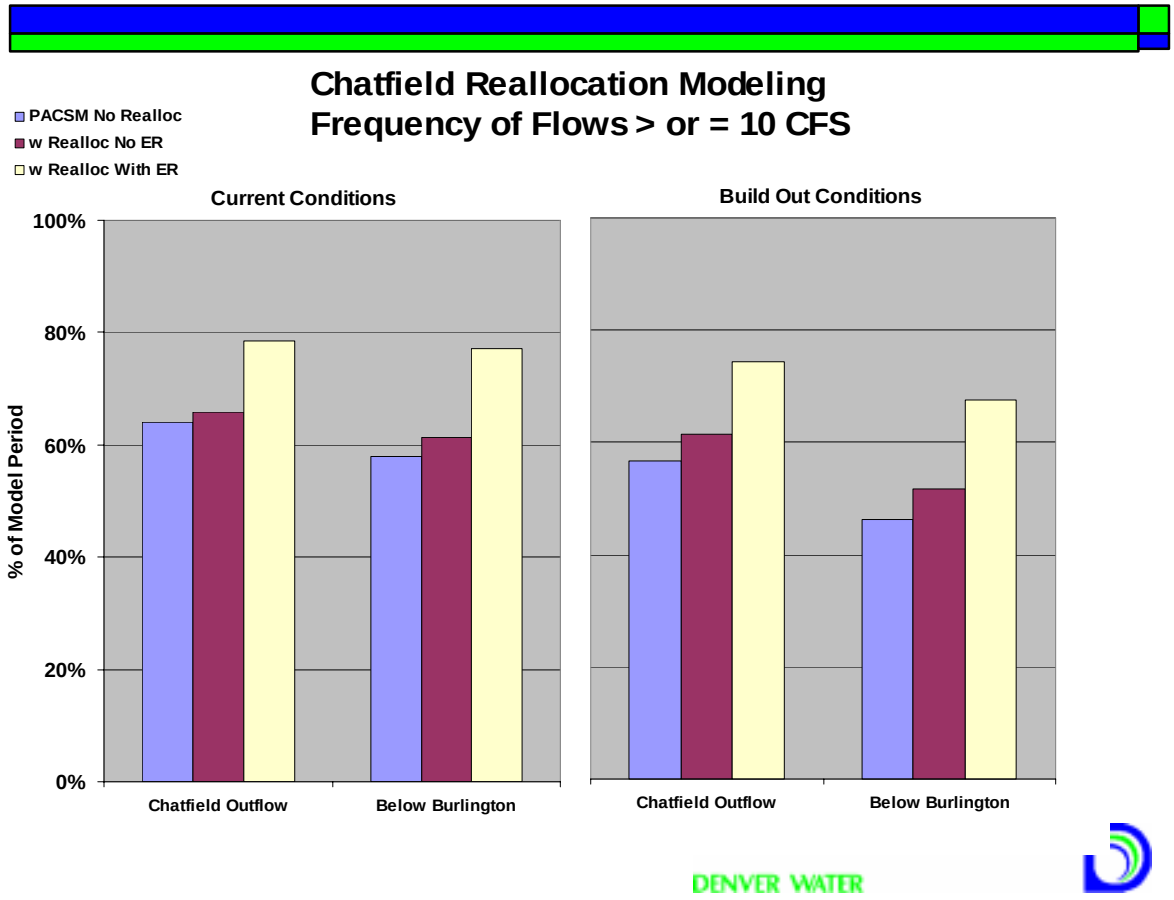
PHABSIM results may have to be amended in the future to allow for a broader analysis to demonstrate other benefits such as those related to migratory birds and water fowl; however, the bird and duck habitat suitability data are not as robust as the fish data, nor is there a process under the current federal authorization for these data to be used to evaluate future environmental conditions along the Platte.

Hydrology

The coupled PACSM and spreadsheet model was able to simulate the various different reservoir release scenarios for Chatfield both with and without the 20,600 acre-feet of reallocated flood storage for both current conditions (2005) and build-out conditions (2050). The results of the simulations indicate, not surprisingly, that capturing South Platte River runoff using the reallocated storage to retime peak flows for release to the downstream users during non-peak periods increases flows during those times when the river at selected places below Chatfield would otherwise be dry or at low flow.

Two locations where the river has historically been observed to have flows below 10 cfs nearly every year includes below the Chatfield Reservoir outfall and below the Burlington Ditch Headgate. Figure 9 presents a graphic representation of how the reallocation will help to decrease the number of days that flow in these two areas drops below 10 cfs.

Figure 9



Based on these results, it can be seen that flows beneath Chatfield are greater than 10 cfs about 60% of the time under current conditions without the reallocation, and will drop to about 55% of the under build-out conditions. With the proposed storage reallocation, the downstream water user specified releases (i.e., with no ER) have incremental benefits to the stream flow below Chatfield. Specifically, the reallocation with the downstream water users EIS specified releases increase by 3 to 12 percent the number of days that have flows below Chatfield and/or below Burlington Ditch at 10 cfs or greater, based on simulations using the 1947 to 1991 hydrology. The greatest incremental benefits related to the flow analyses appear to occur below Burlington Ditch and under build-out conditions; however incremental benefits are shown for both set of watershed conditions (i.e., current and build-out) and at both key locations (i.e., at the Chatfield Outflow and below the Burlington Ditch) with the EIS specified releases.

Another important finding was the ER release scenario, which involved releasing enough water from the reallocated Chatfield Reservoir storage to maintain 10 cfs in the South Platte below Chatfield at key locations (e.g., Chatfield gage and the Burlington gage) substantially decrease the frequency of low flows, especially in the late fall and early winter. The "Reallocation with ER" results provided in Figure 9 illustrate this point. Specifically, the reallocation with ER, which revises the downstream water user releases to address fall and wintertime low flows increases by 23 to 46 percent the number of days that have flows below Chatfield and/or below Burlington Ditch of 10 cfs or greater, based on simulations using the 1947 to 1991 hydrology.

The ER managed flow regime needs to be further characterized with respect to improved and enhanced fish habitat and stream biology, as needed to meet the needs of the instream and water user community; however it is clear that wintertime flow releases can dramatically improve the number of days that the river has greater than 10 cfs flowing in its banks.

Biology

Habitat versus flow relations were developed after the range of flows were simulated within each of the cross sections as presented in Attachment B (note that the actual range of flows included in the cross sections was a broader range than shown in Attachment B). The habitat flow relationships were developed for each of the species of interest by physical reach as indicated in the Table 2.

The resulting habitat flow relationships for each of the physical reaches is presented in Attachment C.

Noteworthy is that for the trout and channel catfish, the flow regime that produces the most habitat is different for juveniles and adults. In general, adults can live in

deeper and faster moving water than the juveniles. Also, many of the fish species were found to have a habitat area that suffers if flows become too large. For non-trout species, a river flow of greater than 100 to 200 cfs was found to have a detrimental impact on habitat area. This was also true for the sand shiner, longnose dace, white sucker and common carp.

Table 2 – Summary of Habitat to Flow Relationships

Physical Reach	Reach Numbers	Species
Southern	1, 2	Rainbow trout (juvenile, adult), brown trout (juvenile, adult), channel catfish (juvenile, adult), sand shiner (adult), longnose dace (adult), white sucker (juvenile, adult), common carp (adult)
Middle	3, 4	channel catfish (juvenile, adult), sand shiner (adult), longnose dace (adult), white sucker (juvenile, adult), common carp (adult)
Northeasterrn	5, 6	channel catfish (juvenile, adult), sand shiner (adult), longnose dace (adult), white sucker (juvenile, adult), common carp (adult)

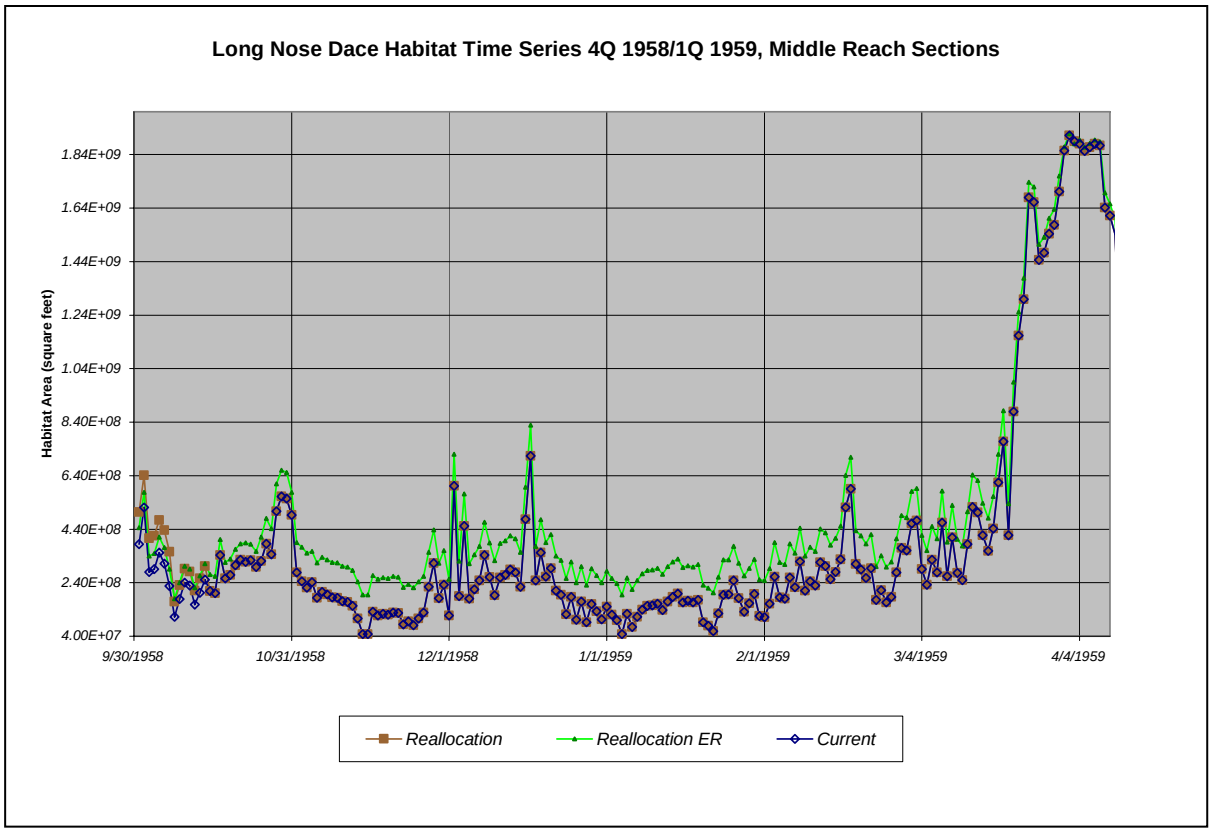
Another important observation was that for trout and channel catfish juveniles and the smaller adult fish (e.g., sand shiner, longnose dace, and white sucker), the biggest jump in habitat area occurs at the lowest flows, especially for flows below 20 to 40 cfs. This same observation held true for common carp, as well. **These observations indicate that protection of low flows with future Chatfield releases may provide substantial benefit to the aquatic fisheries.**

Habitat Area for the Period of Record

The habitat flow relationships were used to convert the predicted stream flows to habitat area over time. And example "hydrograph" of the converted stream flow to habitat area for one of the middle reach sections in 1950 (for the period from June to December) is presented in Figure 10 to illustrate the analysis methodology. This figure illustrates the relative magnitude and timing of the habitat benefits for long nose dace based on the increased flows that occur with each alternative flow scenario. For example, habitat area increases are observed in September and early October when reallocation occurs with the downstream water users EIS releases when compared to the current condition without reallocation. The estimated increases include as much as a doubling of habitat area for selected days, or more; and the benefits are seen to last for 5 to 6 weeks.

The increased habitat area created by the reallocation ER releases on the other hand, occur throughout September, October, November and December, since the release rate is lower under this flow scenario, and it is timed to benefit the fall and winter flow period.

Figure 10



Once the habitat area had been estimated over time for each species and sub-reach, total habitat area was calculated versus percent exceedances for each species over the entire study area to contrast and compare the incremental benefits of the potential future reallocated storage release scenarios on the fishery habitat. Table 3 presents the results of the total habitat area calculation for selected periods of exceedance for each of the species.

Table 3 – Summary of Total Habitat Area Impact versus Percent Exceedance (in percent)

	Channel Catfish				White Sucker				Carp		Sand Shiner		Longnose Dace		Brown Trout				Rainbow Trout			
	w/o ER		w/ ER		w/o ER		w/ ER		w/o ER	w/ ER	w/o ER	w/ ER	w/o ER	w/ ER	w/o ER		w/ ER		w/o ER		w/ ER	
%	J	A	J	A	J	A	J	A	A	A	A	A	A	A	J	A	J	A	J	A	J	A
80	.07	.03	3.6	11.	0.0	0.0	3.5	3.5	0.2	3.1	0.0	28.	0.8	6.0	0.0	0.0	126	163	0.0	0.0	153	117
70	0.5	4.4	0.2	13.	1.1	1.1	4.2	4.2	0.0	10.	2.0	25.	1.4	5.3	31.	40.	75.	97.	39.	29.	91.	70.
60	3.1	6.9	2.1	5.0	3.9	3.9	2.9	2.9	1.0	13.	2.2	7.6	3.3	2.9	28.	41.	22.	33.	26.	33.	21.	26.
50	0.9	1.1	.07	1.0	1.7	1.7	3.0	3.0	0.6	1.0	1.3	0.0	1.3	1.3	1.4	6.4	1.7	7.2	1.4	6.4	2.0	7.0

J – juvenile; A – adult

Figure 11 presents the total habitat area versus percent exceedance curves for four different fish to illustrate how the incremental impacts of retimed flow beneath Chatfield improve fish habitat.

Figure 11 and the contents of Table 3 illustrate that for all fish evaluated, which include all those fish that the DOW considers to be of state interest that are contained in the South Platte River, **habitat area can be improved with future reallocated storage releases** for some return period, typically during dry periods that occur from once in every two years (50%) to once in every five years (80%).

The greatest habitat improvement, based on percent increases in habitat area, was estimated to occur for the cold water species - brown and rainbow trout. For the return period of between once in every three years to once in every five years, habitat areas increased with future reallocated Chatfield storage releases by 21 to 153 percent for juveniles and 26 to 163 percent for adults, depending on species and return period. Adult trout habitat area appears to benefit most from retimed flows that occurred in the once out of every five years return period (i.e., 80 percent exceedance), whereas juvenile trout habitat area appears to benefit most from retimed flows in the once out of every three year return period. Juvenile habitat area does not appear to benefit from the retimed flows for the once in five year return period.

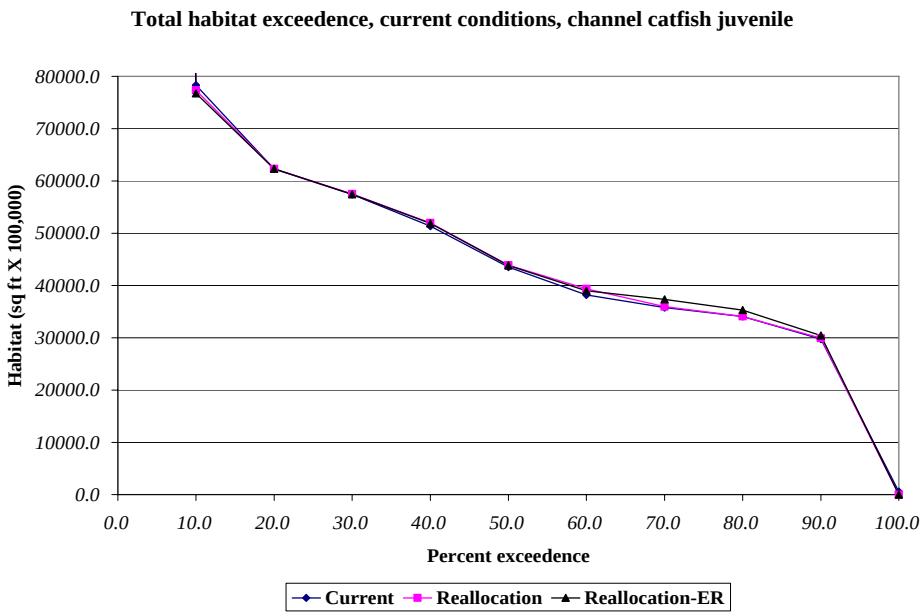
The biggest habitat area improvements for the cool and warm water species, based on percent increase in habitat area, typically occurred at the 60 or 70 percent exceedance for juveniles and the 80 percent exceedance for adults, in a manner consistent with the trout habitat; however the percent increase in habitat area for each of these species was estimated to be substantially less than that for trout, ranging from 0 to 28 percent. Nonetheless **there is a measurable increase in habitat area for all fish species due to the retimed releases from Chatfield.**

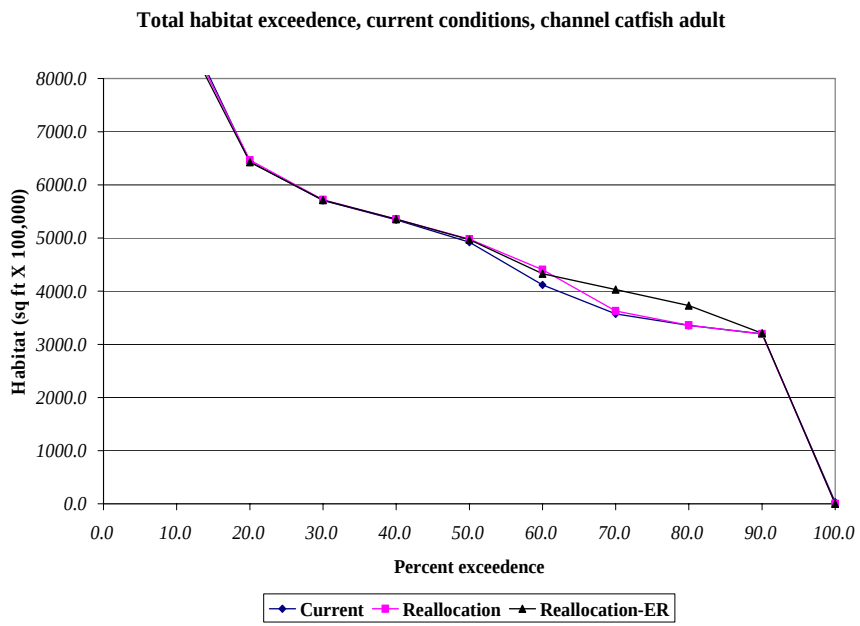
These preliminary findings also indicate that for most species of interest, the habitat area benefits related to the future reallocated storage releases can be improved by releasing low flows in the fall and winter months versus having releases during the summertime as currently indicated by the water user release scenarios contained in the EIS. There are some return periods for some species where the water user defined releases are as good if not better at enhancing fishery habitat below Chatfield than the "ER" releases (e.g., at 60% exceedance for white suckers), but these circumstances are the exception rather than the rule.

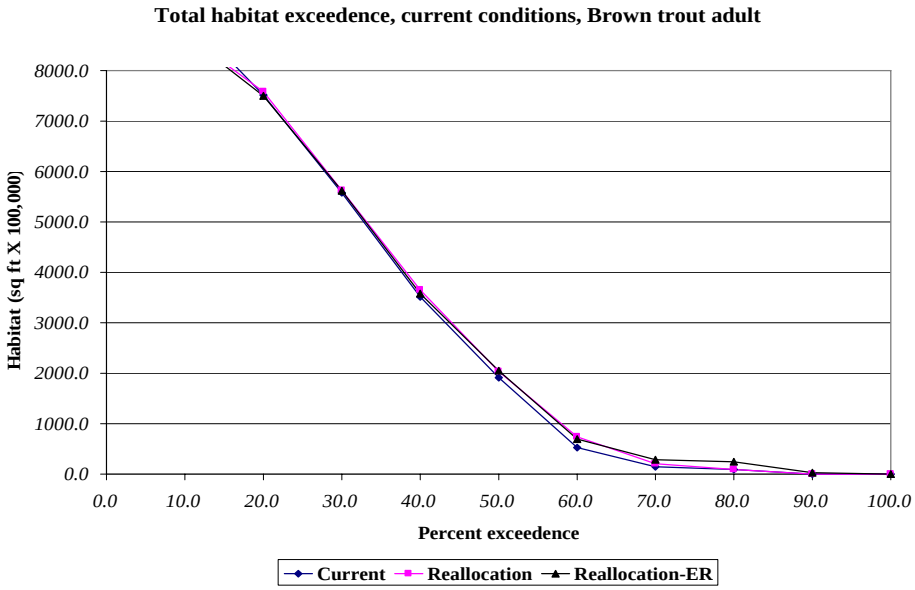
Wet and Average Conditions Analyses

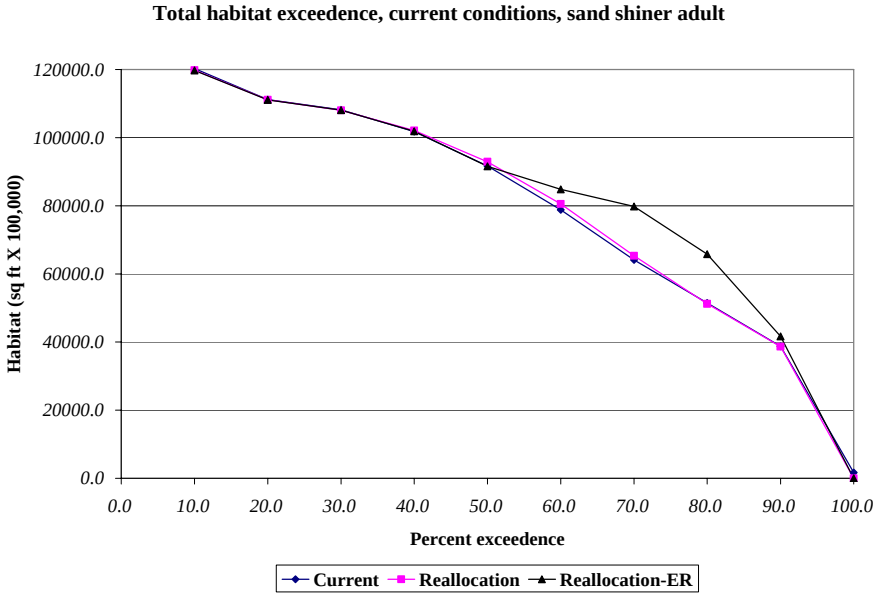
To more fully characterize the benefits of ER releases on the downstream fisheries habitat, habitat areas were calculated using composite hydrographs of average and wet river flow conditions developed using the following procedures:

Figure 11


Total habitat exceedence, current conditions, channel catfish juvenile
Habitat (sq ft X 100,000)
80000.0
70000.0
60000.0
50000.0
40000.0
30000.0
20000.0
10000.0
0.0
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0
Percent exceedence
Current
Reallocation
Reallocation-ER


Total habitat exceedence, current conditions, channel catfish adult
Habitat (sq ft X 100,000)
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0
Percent exceedence
Current
Reallocation
Reallocation-ER


Total habitat exceedence, current conditions, Brown trout adult
Habitat (sq ft X 100,000)
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0
Percent exceedence
Current
Reallocation
Reallocation-ER


Total habitat exceedence, current conditions, sand shiner adult
Habitat (sq ft X 100,000)
120000.0
100000.0
80000.0
60000.0
40000.0
20000.0
0.0
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0
Percent exceedence
Current
Reallocation
Reallocation-ER

- An average daily flow was calculated for each river year (1947 to 1991) based on the hydrographs developed for current and build-out conditions under both the water user specified releases and the ER releases described in the subsection on hydrology.
- The average daily flow for each river year were ranked and segregated into the nine wettest years (representing the wettest 20% of years) and nine average years (representing the middle 20% of years) as shown in Figure 12.
- Composite wet year and average year hydrographs were developed at the Chatfield and Burlington gages for both current and build-out conditions for the water user specified releases and the ER releases by taking the average flow for each day using the nine years of data identified through the ranking process.

The composite wet year and average year hydrographs for the various flow conditions are presented in Figures 13a (current conditions) and 13b (build-out conditions).

Figure 12

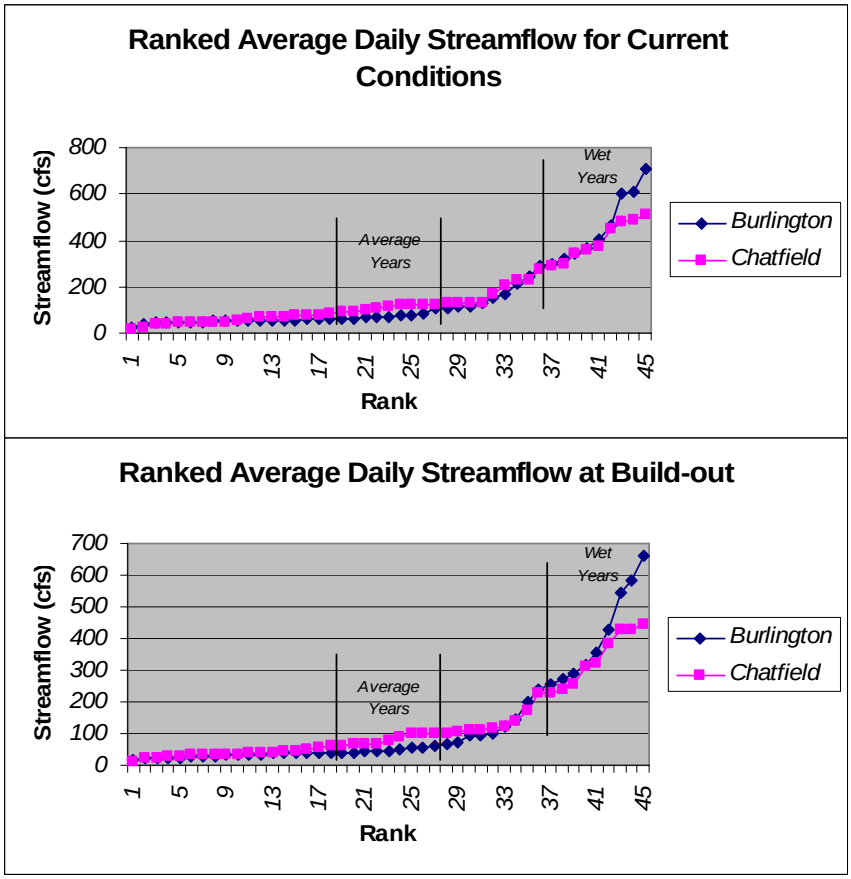
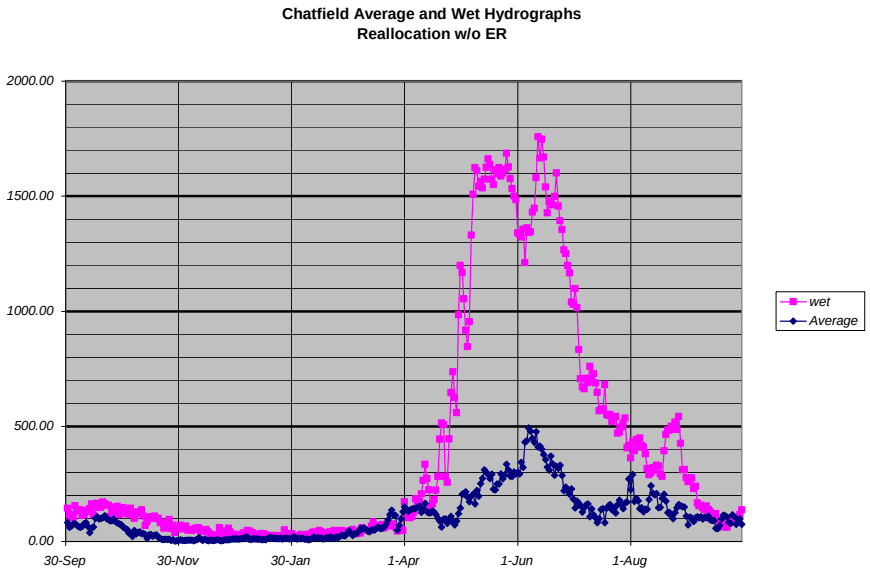
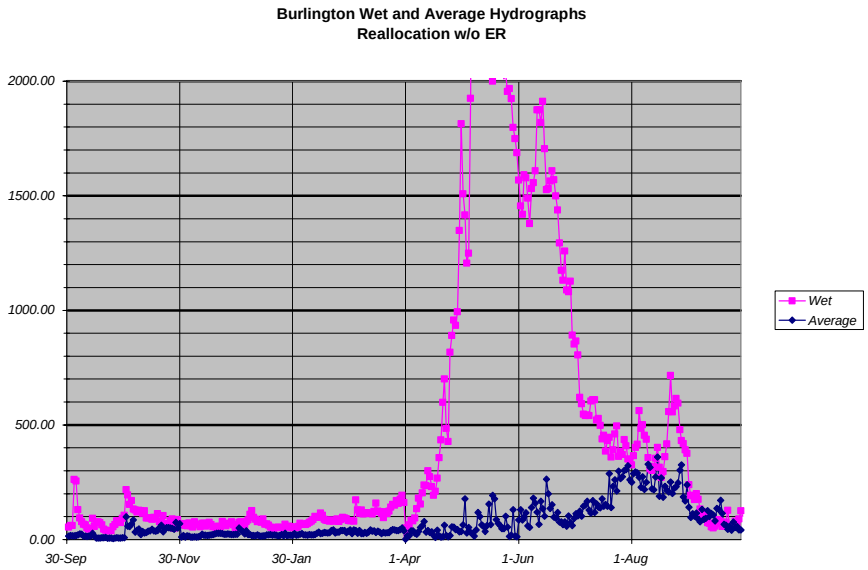
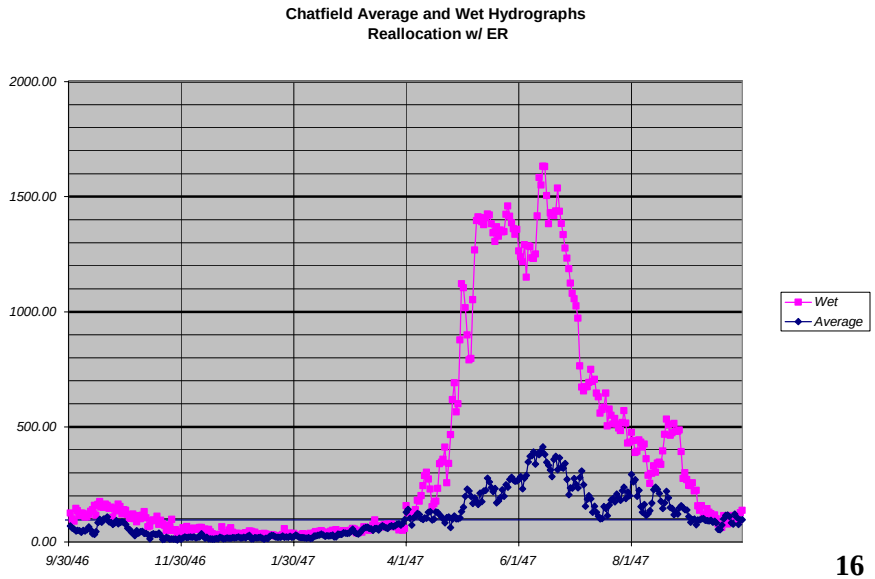


Figure 13a - Current Conditions







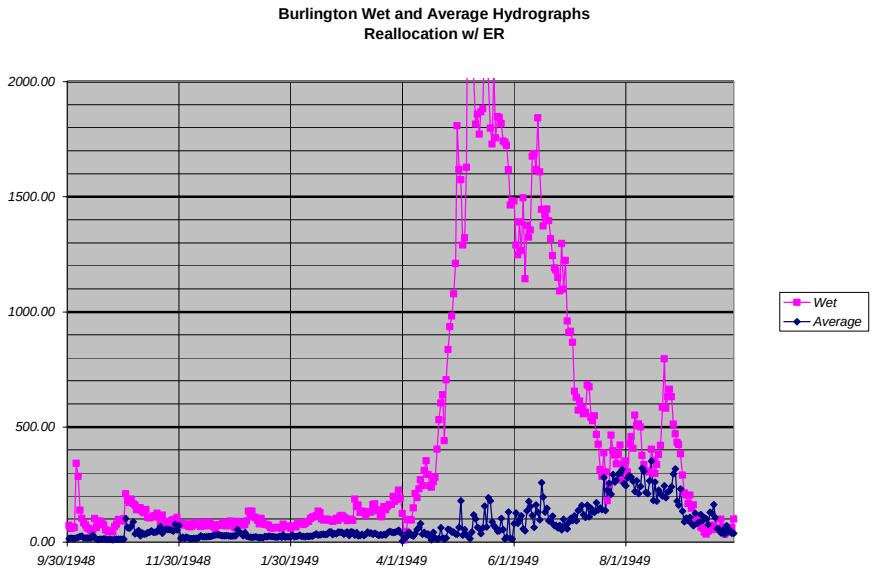
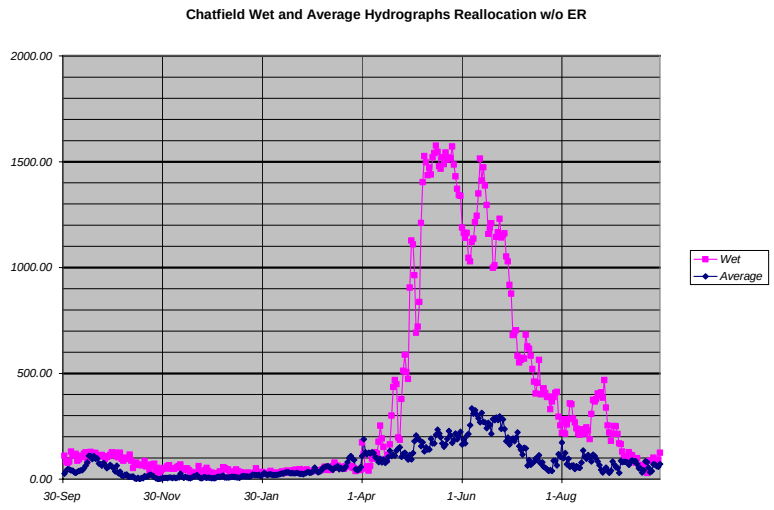
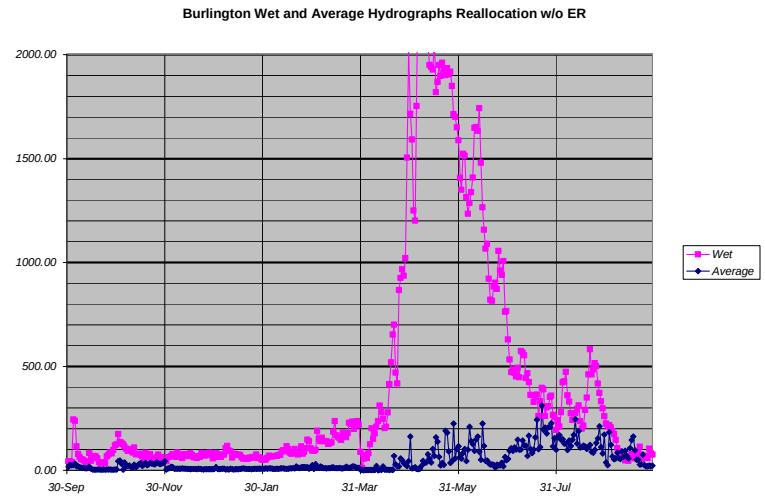
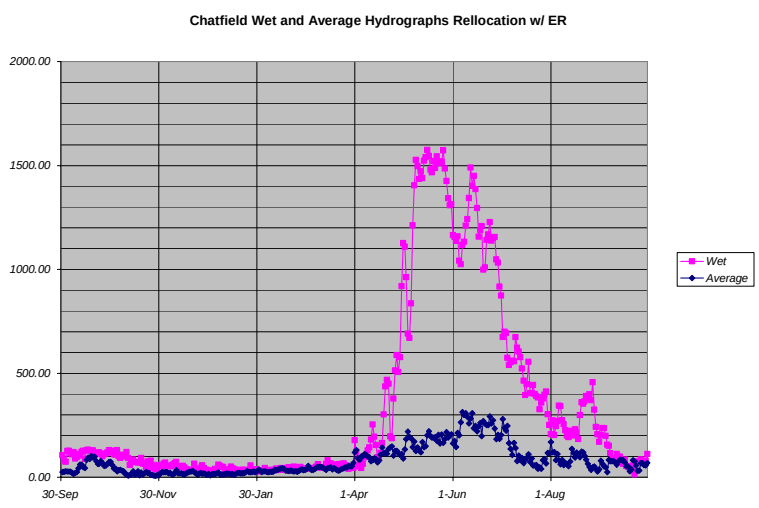
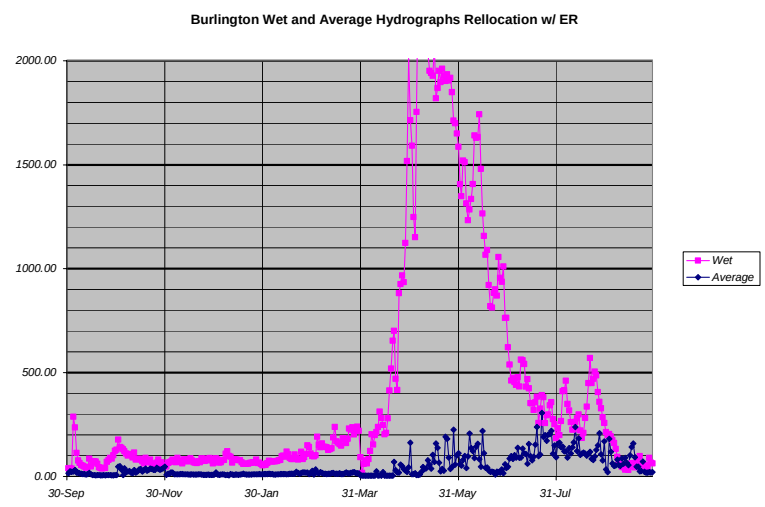


Figure 13b – Build-Out Conditions









Composite hydrographs were only created at the Chatfield and Burlington gages since these two gages historically demonstrate the lowest wintertime flows in the South Platte below Chatfield due to the configuration of the South Platte and its tributaries and wastewater plant discharges. Therefore these two gages are the most sensitive gages to the proposed ER releases of those gages that currently exist below Chatfield Reservoir. For this reason, the ER releases from Chatfield Reservoir into the South Platte River will provide the greatest incremental benefits to fish habitat at the Chatfield and Burlington gage reaches. Increased habitat areas at these two locations not only will enhance fish populations locally, but may also serve to improve the connectivity of isolated fish populations both upstream and downstream of these localities.

Habitat time series simulations were made for each of the species of interest, including juvenile and adult life stages, based on the habitat versus discharge data presented in Attachment C. Specifically, the following simulations were made:

- Chatfield Gage
  - Reallocation without ER
    - Current conditions – wet and average hydrology
    - Build-out conditions – wet and average hydrology
  - Reallocation with ER
    - Current conditions – wet and average hydrology
    - Build-out conditions – wet and average hydrology
- Burlington Gage
  - Reallocation without ER
    - Current conditions – wet and average hydrology
    - Build-out conditions – wet and average hydrology
  - Reallocation with ER
    - Current conditions – wet and average hydrology
    - Build-out conditions – wet and average hydrology

The results of the Habitat time series modeling for these various simulations are presented in Attachment D. These results are summarized below.

The greatest improvements to habitat area associated with the wintertime ER releases generally occur during the average condition flow regimes, for both current and build-out conditions (Table 4). This is understandable since the flows are substantially lower (four to ten times lower) during average years then during wet years, making the impact of the 10 cfs wintertime releases associated with the ER more pronounced on the river's fish species. There are also benefits to habitat area during wet years associated with the ER releases given that late fall and wintertime low flows are bolstered during those situations when flows at the Chatfield and Burlington gages are below 10 cfs.

Table 4 - Summary of Percent Habitat Area Changes with ER versus Water Supply User Specified Releases Given Reallocation of Chatfield Storage of 20,600 Acre-Feet

	Current Conditions				Build-Out Conditions			
	Winter*		Summer**		Winter*		Summer**	
	average	wet	average	wet	average	wet	average	wet
Chatfield								
Juvenile								
Brook Trout	47.03%	6.57%	-1.60%	-1.27%	33.90%	5.80%	0.70%	0.40%
Channel Cat	-37.93%	4.60%	-6.13%	-0.77%	-19.60%	5.37%	-0.63%	-0.10%
Adult								
Brook Trout	60.53%	6.57%	3.13%	-0.70%	45.70%	13.00%	2.67%	-0.83%
Channel Cat	55.10%	7.07%	4.10%	-0.53%	40.43%	7.53%	3.10%	-1.10%
Longnose Dace	42.00%	7.10%	0.97%	-0.97%	30.40%	7.47%	1.77%	-0.23%
Burlington								
Juvenile								
Channel Cat	8.67%	-0.37%	-0.53%	-2.37%	22.00%	-0.03%	-1.47%	-1.00%
White Sucker	30.37%	8.17%	0.00%	-0.23%	75.47%	3.17%	-12.80%	0.03%
Adult								
Channel Cat	16.43%	10.70%	-0.57%	-1.97%	28.10%	4.03%	-4.37%	-0.53%
White Sucker	30.37%	8.17%	0.00%	-0.23%	75.47%	3.17%	-12.80%	0.03%
Longnose Dace	15.57%	10.73%	-2.60%	-2.37%	31.87%	3.93%	-5.77%	-1.10%

Table presents the percent change in habitat area caused by the ER releases versus the Water Supply User Specified releases

*** winter is the average percent habitat area increase for the months December, January and February**

**** summer is the average percent habitat area increase for the months June, July and August**

Of all the species evaluated, only juvenile channel catfish are found to have their habitat area decrease due to the wintertime flow releases. This observation relates directly to the habitat flow relationship that exists for juvenile channel catfish, as indicated in Attachment B. Juvenile channel catfish have a marked habitat area reduction when flow increases above 10 cfs, based in part upon this fish's lack of tolerance for water deeper than 2 feet. Given that the South Platte River has incised banks due to its lack of sediment transport, the juvenile channel catfish will benefit from those periods when the South Platte has dry years, and the other fish, including the adult channel catfish will benefit during average and wet years.

The benefits of the ER release scenario on summertime fish habitat is not nearly as distinct. For the months of June, July and August, only a marginal improvement or decline in habitat area is estimated for the species of interest (with the possible exception of the white sucker under build-out conditions in the vicinity of the Burlington gage). This is presumably due to the fact that flows in these summer months, which are on the declining side of the seasonal peak flows in the South Platte, occur during a time when the water supplier customers have the greatest demand for water. Therefore, the water supplier specified releases occur during this time period placing additional flow in the South Platte improving habitat area. However, habitat area in the summer is already three to as much as twenty times greater in the summer than in the winter, so the small reductions in habitat area associated with the ER release scenario are not considered significant or detrimental to the fish species of interest during this time of year.

Section 4
Key Observations and Recommendations

Observations

The key observations that were established based on the hydrologic and biological habitat modeling performed during this study are as follows:

- **There is a measurable increase in habitat area for all fish species due to the retimed releases from Chatfield.**
- **For all fish evaluated**, which include all those fish that the DOW considers to be of state interest that are contained in the South Platte River, **habitat area can be improved with future reallocated storage releases** for some return period..
- These preliminary findings also indicate that for most species of interest, the **habitat area benefits related to the future reallocated storage releases can be improved by releasing low flows in the fall and winter months** versus having releases during the summertime as currently indicated by the water user release scenarios contained in the EIS.
- **The most marked benefits associated with fall and winter month releases occur during average flow years on the River**, when water is available to fill the reallocated storage pool and the river is flowing at levels 4 to 10 times lower than during wet years. During the wet years, the fish habitat is typically 3 to 5 times (300 to 500 percent) greater than during average years, so it is during the average years when the habitat improvements are most needed.
- Additional analyses are needed to better characterize the value and effect of alternative ER releases on the downstream fish habitat; however, **it is clear that retimed South Platte River flows can substantially improve fish habitat downstream of Chatfield, and that fall and winter time releases are more beneficial than summertime releases as proposed by the water users in the EIS.**

Recommendations

The benefit of ER releases provides a number of opportunities for the water users to improve ecological conditions in the South Platte River below Chatfield. Not only will the fish habitat be improved by the releases, but other flora and fauna dependant and/or coexisting with the fish species of interest, including migratory songbirds and water fowl, birds of prey and various mammals that live in and along the South Platte River riparian corridor could benefit from the increased fall and winter time flows in those river reaches where flows fall beneath 10 cfs on a regular and at times prolonged basis.

However, benefits to the water users and other Chatfield reallocation project stakeholders extend beyond the ecological. Specifically, **utilizing some portion of the reallocated storage space in Chatfield for ecosystem restoration purposes may also afford significant cost savings to the State and the water users** relate to:

- The capital cost of storage; and
- The environmental and recreational mitigation costs of the reallocation.

With respect to the capital cost of storage, USACE has indicated at numerous planning meeting held in 2006 and 2007 that the portion of the reallocated storage pool that will be dedicated to downstream ER benefits may be deducted from capital costs associated with the storage volume approved for reallocation from the flood storage pool. **This deduction would in essence provide the water users with a credit of millions of dollars against the overall reallocation project cost** - a credit that would not require a federal appropriation to obtain, since no federal expenditures would be needed for the credit to be given. It is possible that the credit could be provided via an approval from the Assistant Secretary of the Army during the review of the Reallocation Study Feasibility Report (FR).

Further discussion of the processes required to obtain the credit with Omaha, Portland, and USACE HQ is needed to fully characterize the review and approval process; however the cost of these discussions and the impact of the discussions on the EIS being completed is not excepted to be significant at this time.

With respect to the mitigation costs, reservoir releases that reduced the speed and magnitude of reservoir fluctuations during key seasonal periods (e.g., during the summer when park usage is at its peak) may reduce overall mitigation costs related to both environmental and recreational impacts. Although USACE has indicated that an ER "credit" may be available to offset mitigation costs, such a credit would require a federal appropriation, and therefore may be years away. The more directed and locally controlled approach would involve using the ER analyses presented herein, as a stepping stone to aide in the design and implementation of both the environmental and recreational mitigation projects, such that **reservoir fluctuations could be evaluated and characterized along with downstream ER benefits in a manner that reduces future mitigation costs.**

Inclusion of the benefits of ER into the overall reallocation project will require a high level of water user cooperation and collaboration. The use of the ER benefits to reduce the capital cost of storage will require quick action to allow discussions with USACE Omaha, Portland and HQ to occur within the next few months such that the reallocation FR can be appropriately modified and amended. The process for influencing the FR is not necessarily costly, but it is time sensitive.

The inclusion of the ER into the mitigation design efforts is altogether more involved and challenging. Numerous issues will influence how the ER is brought into the design effort, not the least of which is the manner in which the EIS and ROD are crafted to allow for multiple future reservoir operations to occur. Early inclusion of these discussions with the CWCB, State Parks and USACE as the EIS is developed will likely benefit the effort. If the key parties agree to include ER analyses in the design and reservoir operations evaluations, additional analyses will likely be needed to best determine how mitigation costs may best be reduced through future ER releases.

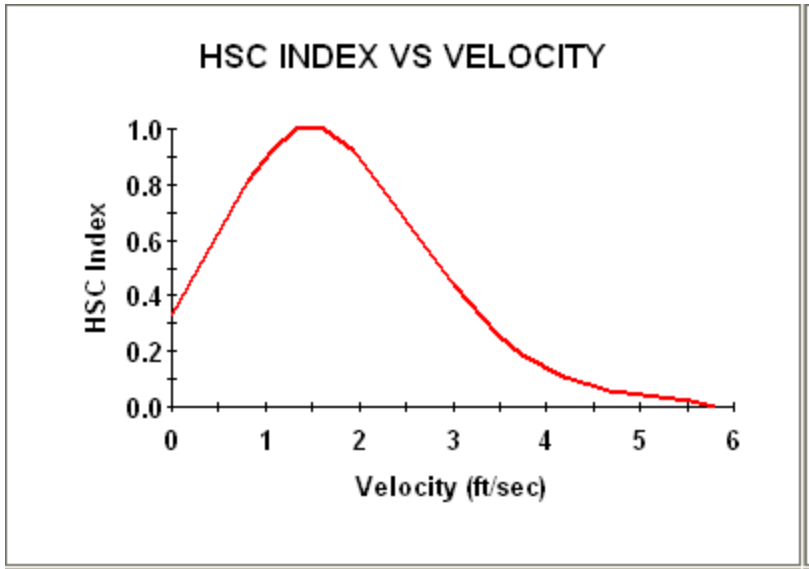
Attachment A

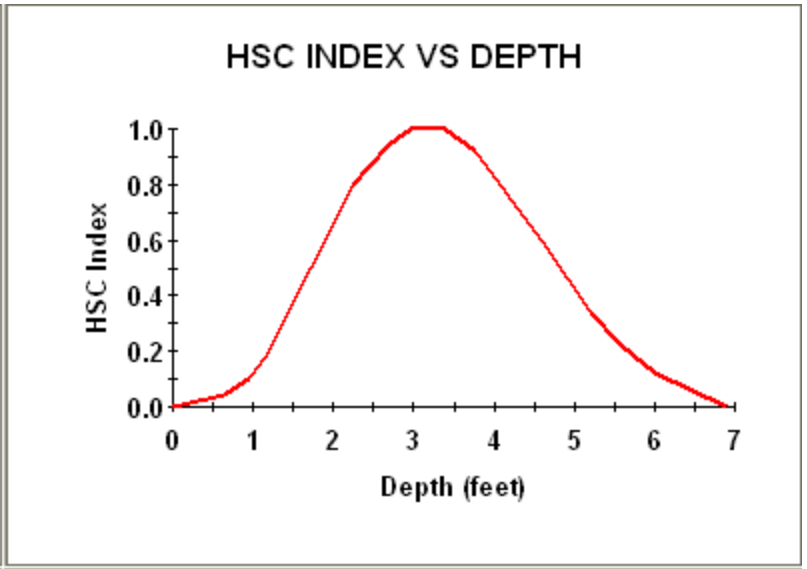
Habitat Suitability Data for Species of Interest

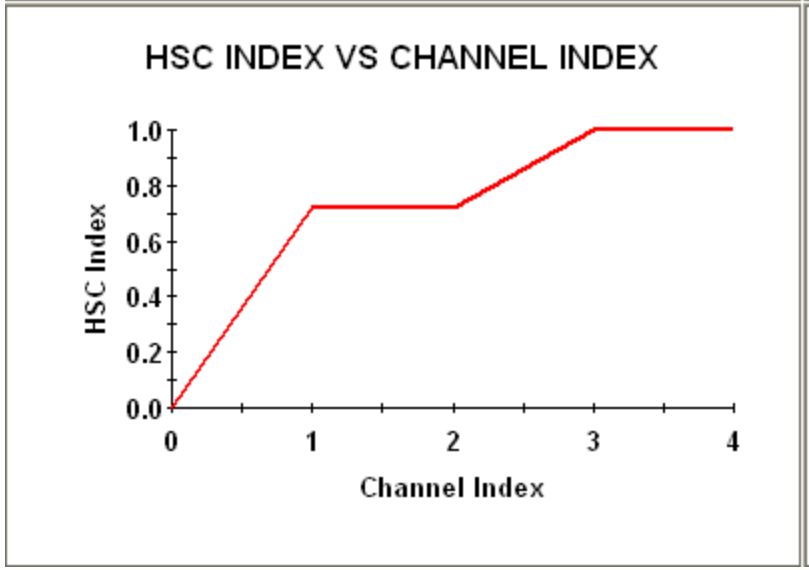
Habitat Suitability Criteria

- All data from published studies or Colorado studies
- Sources:
  - Brown and Rainbow Trout - CDOW South Platte River
  - Channel catfish, adult – Peters et al. 1989 – Platte River
  - Channel catfish juvenile – Chadwick Platte River
  - Common carp adult - Chadwick Platte River
  - Sand shiner - Chadwick Platte River
  - Longnose dace – USFWS HSI criteria
  - White sucker - USFWS HSI criteria

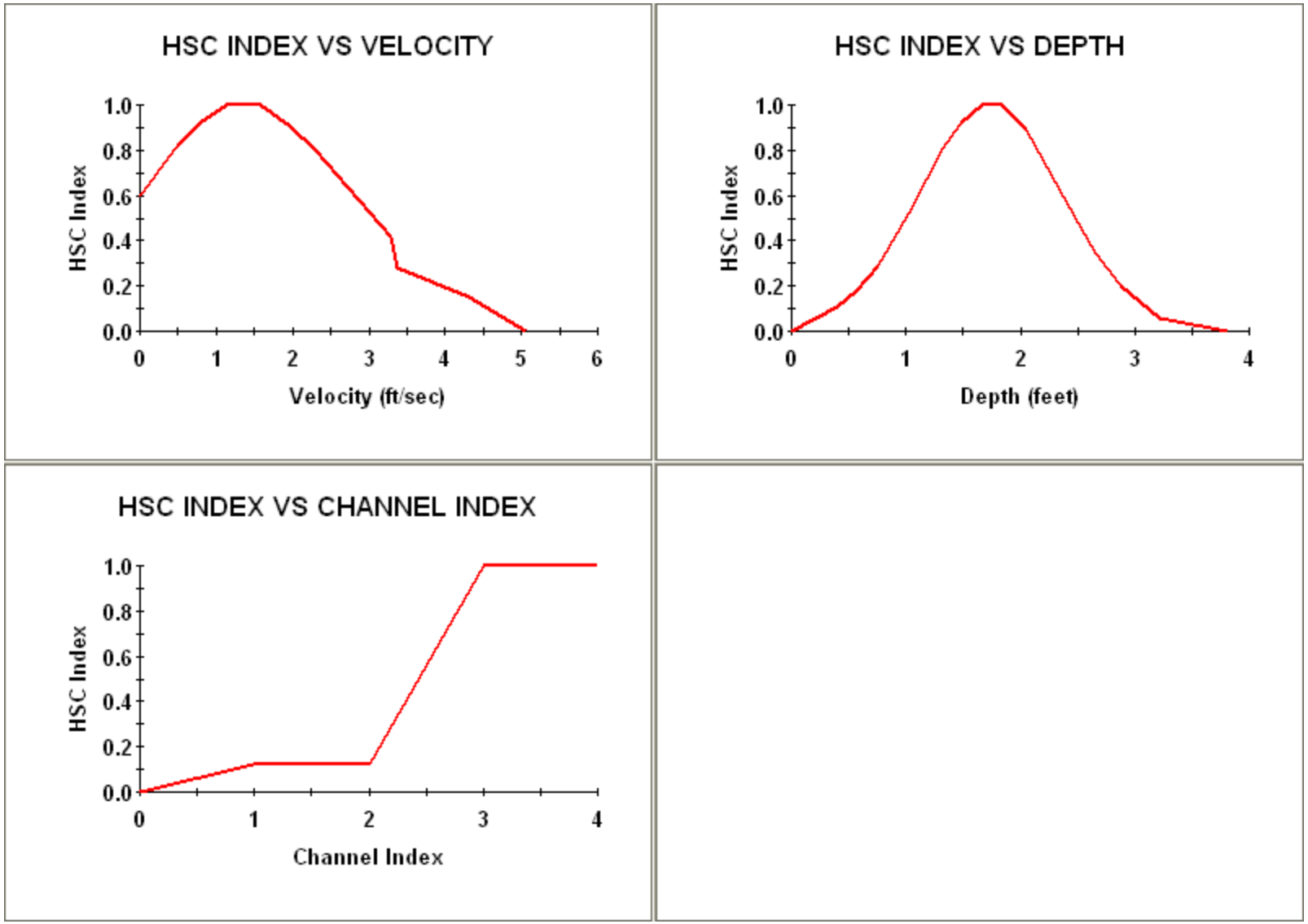
Brown Trout - Adult



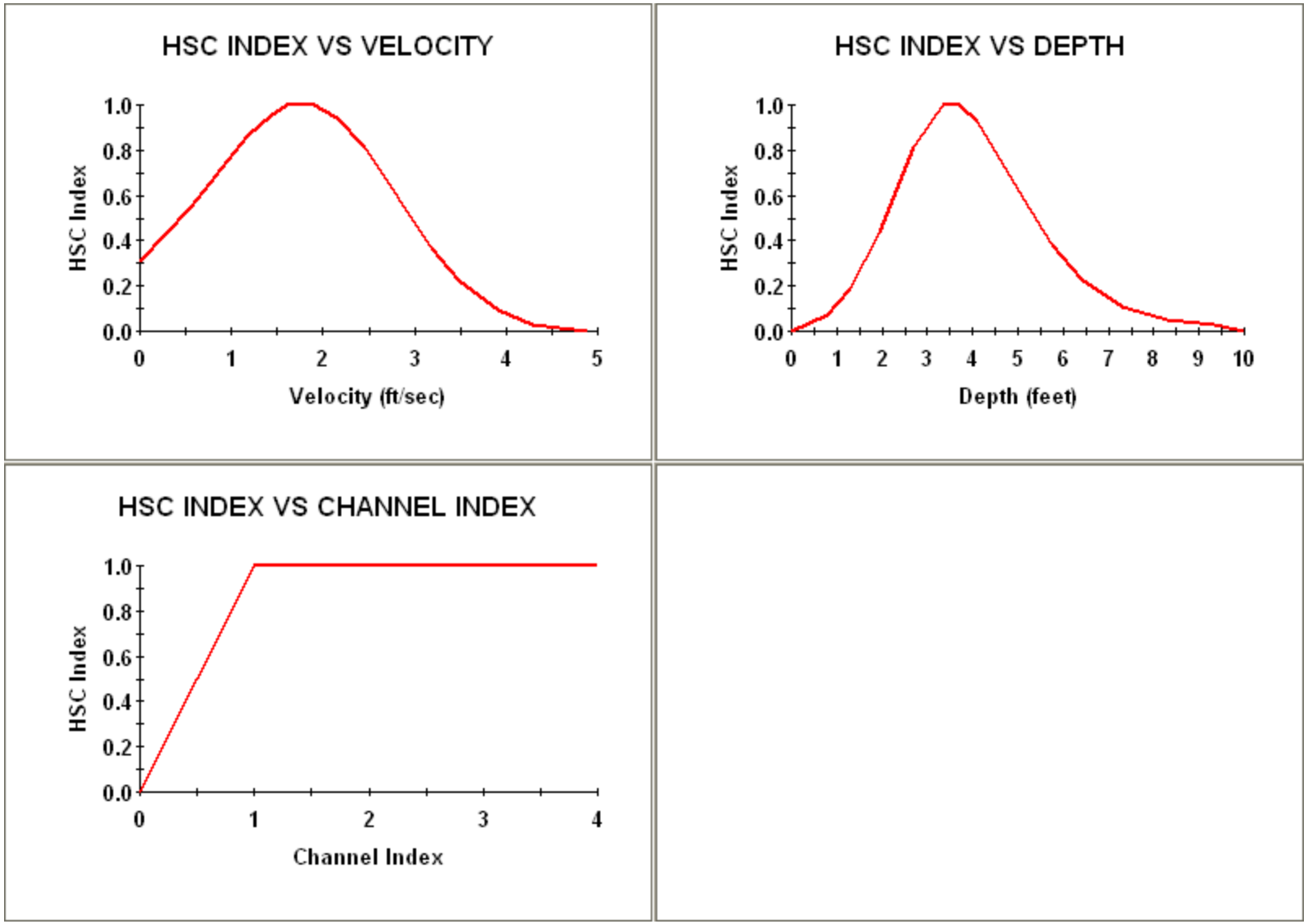




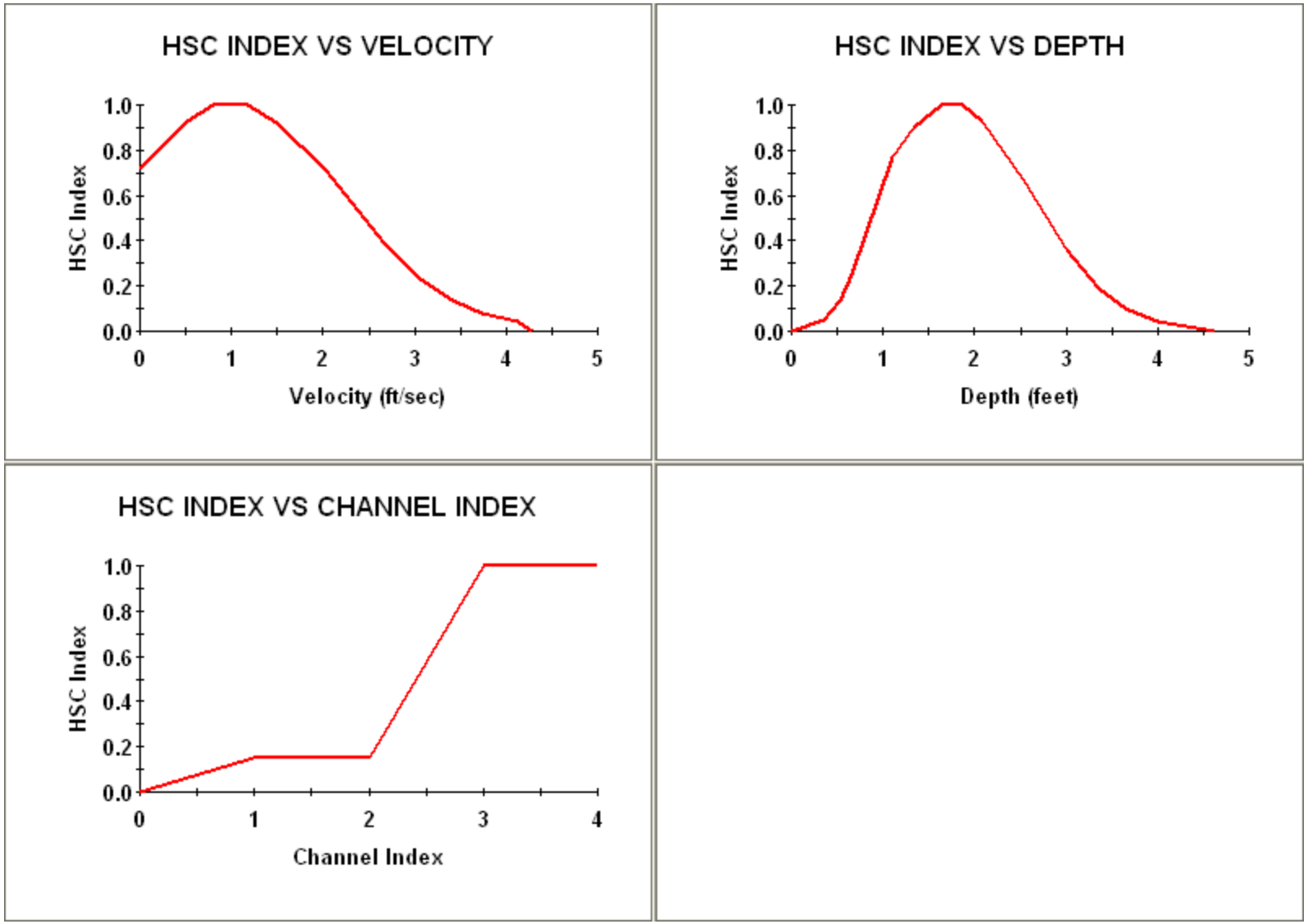
Brown Trout - Juvenile



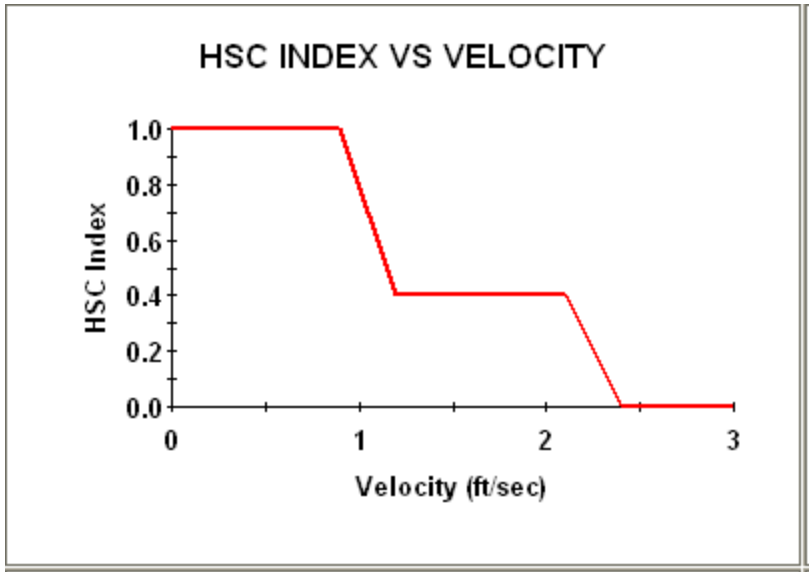
Rainbow Trout - Adult

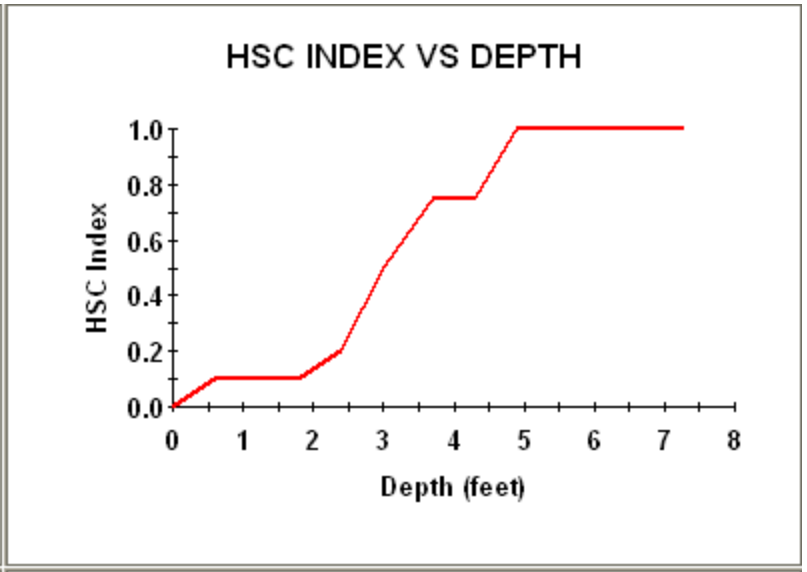


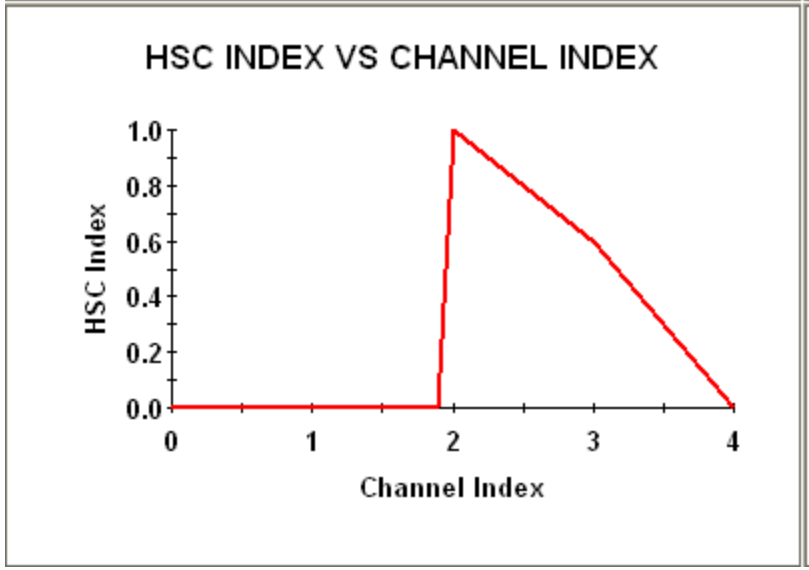
Rainbow Trout - Juvenile



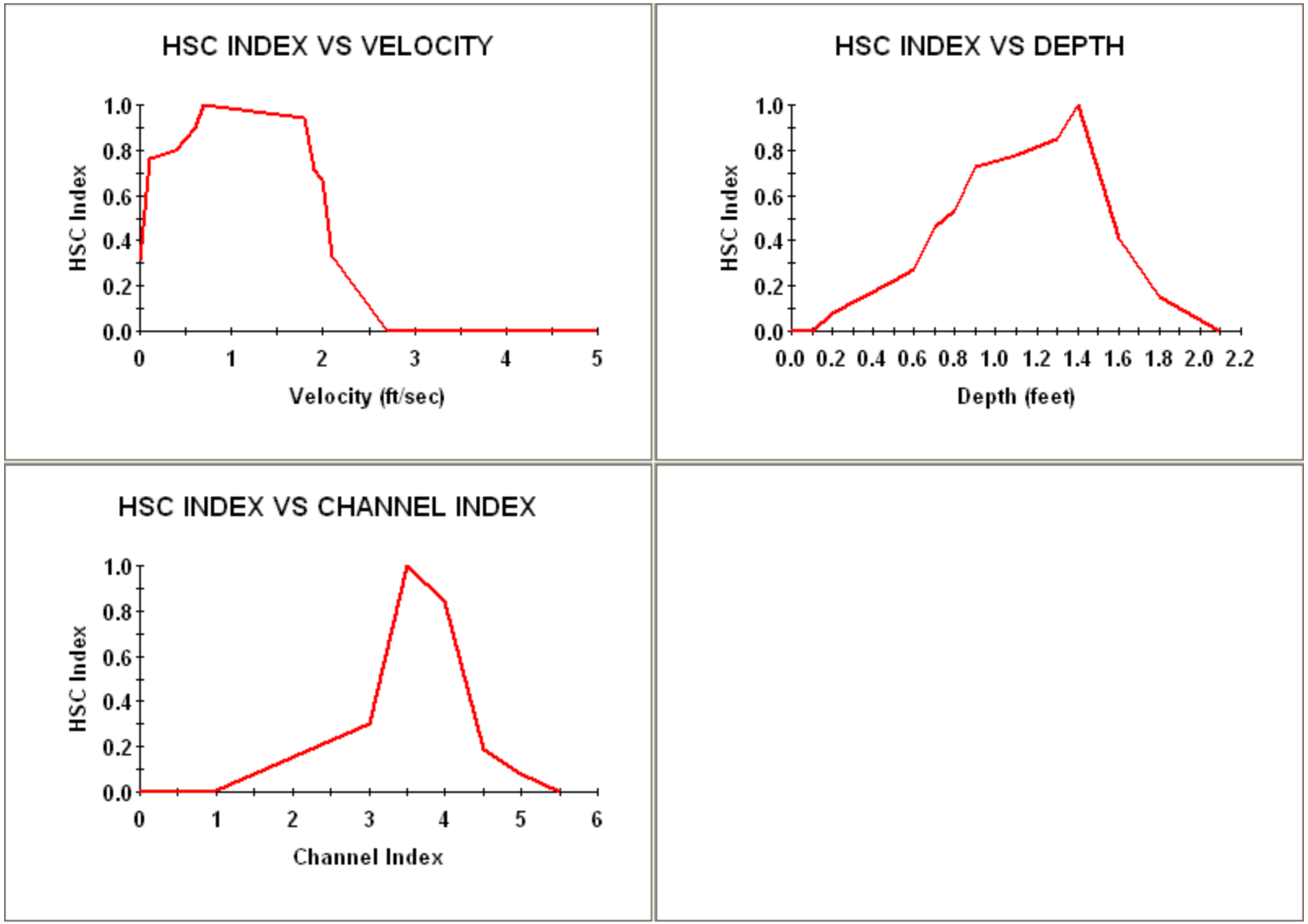
Channel Catfish - Adult



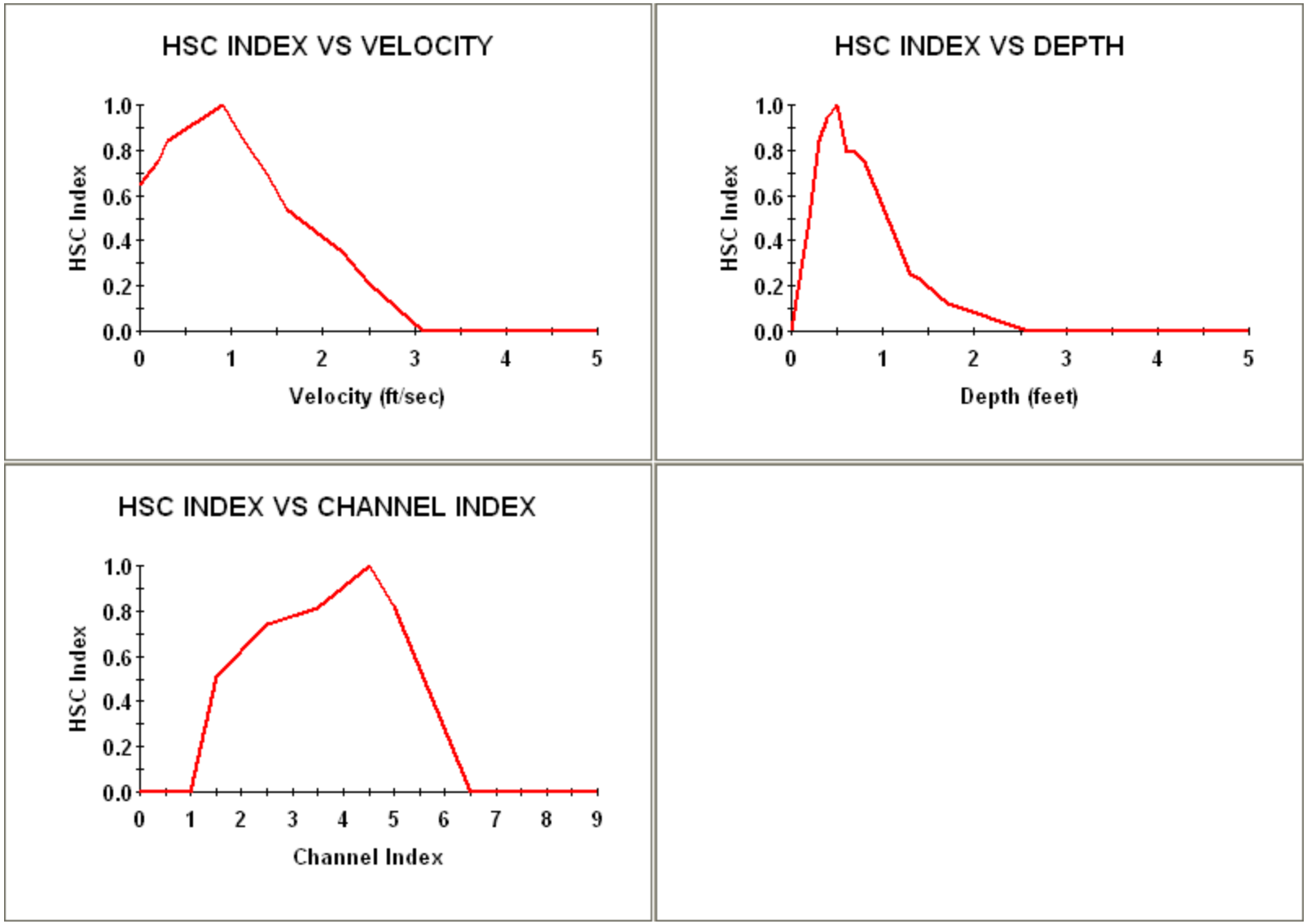




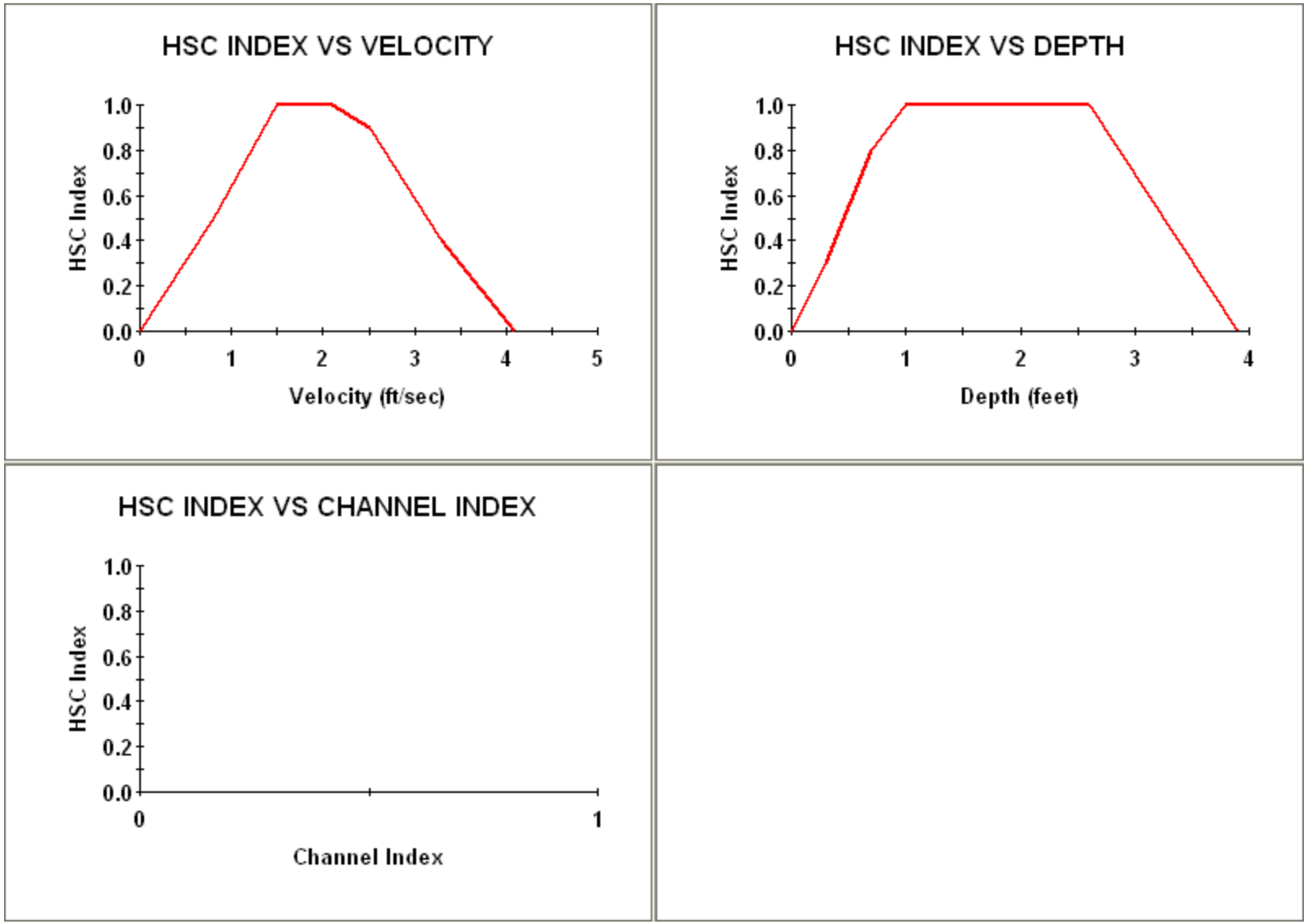
Channel Catfish - Juvenile



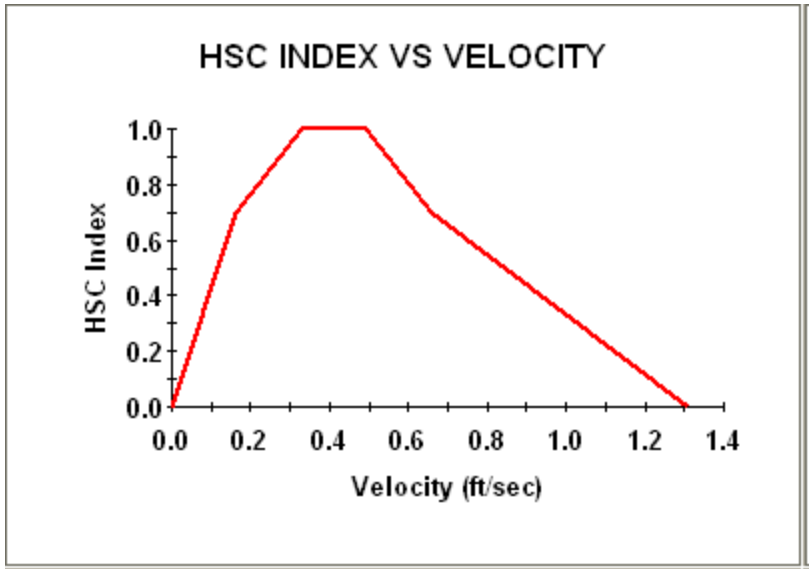
Sand Shiner - Adult

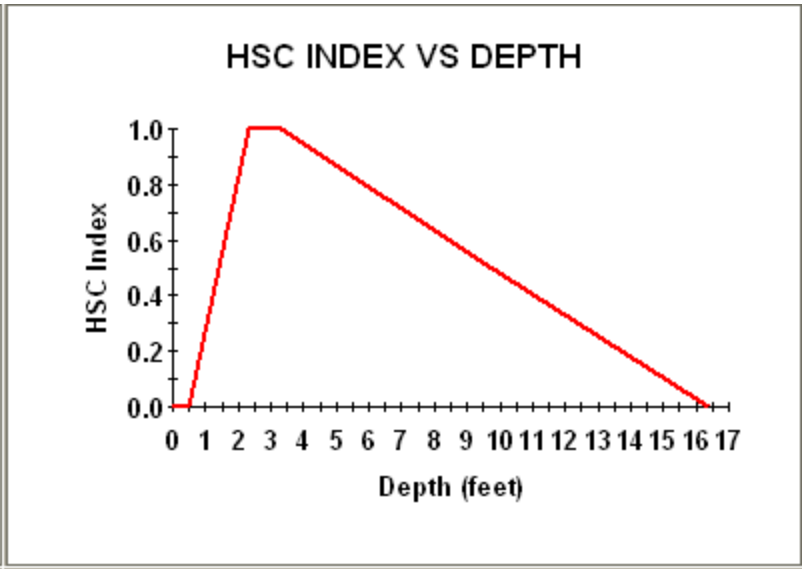


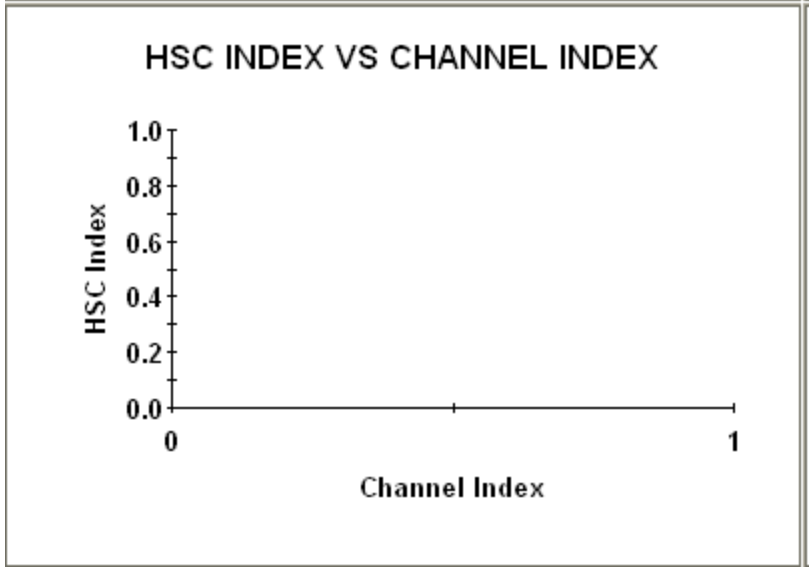
Longnose Dace - Adult



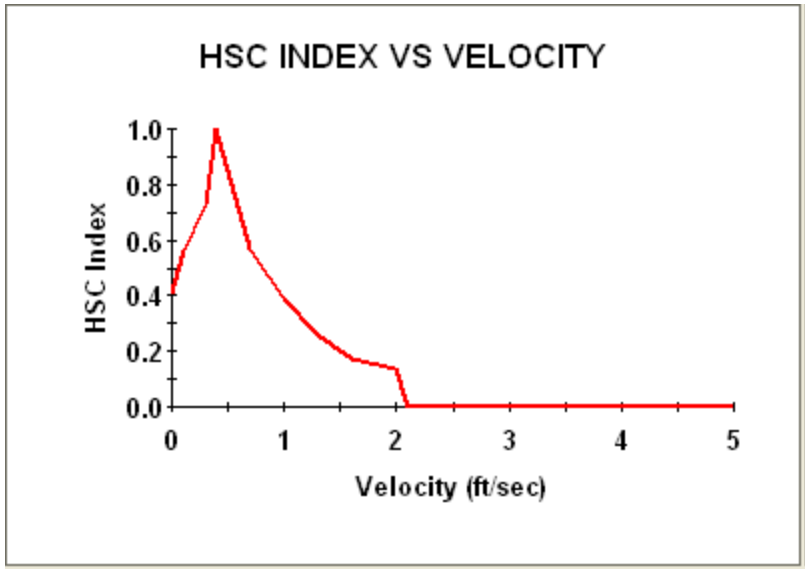
White Sucker – Juvenile/Adult

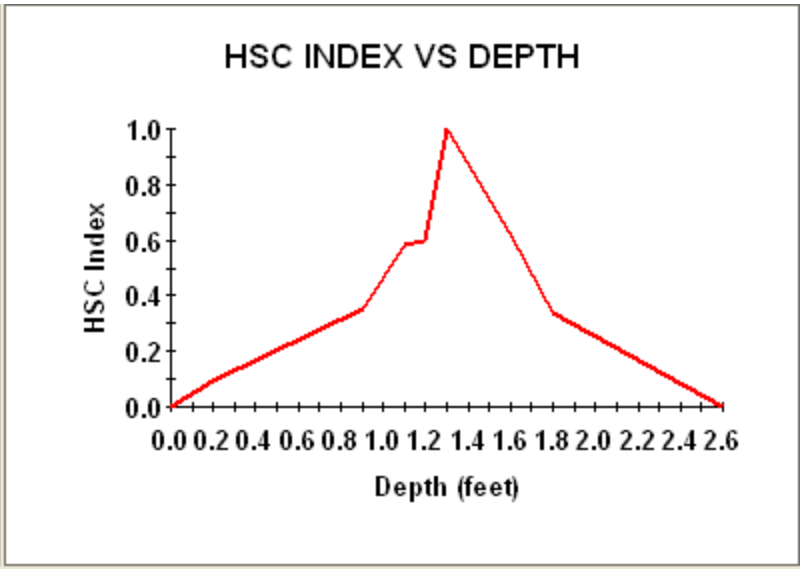


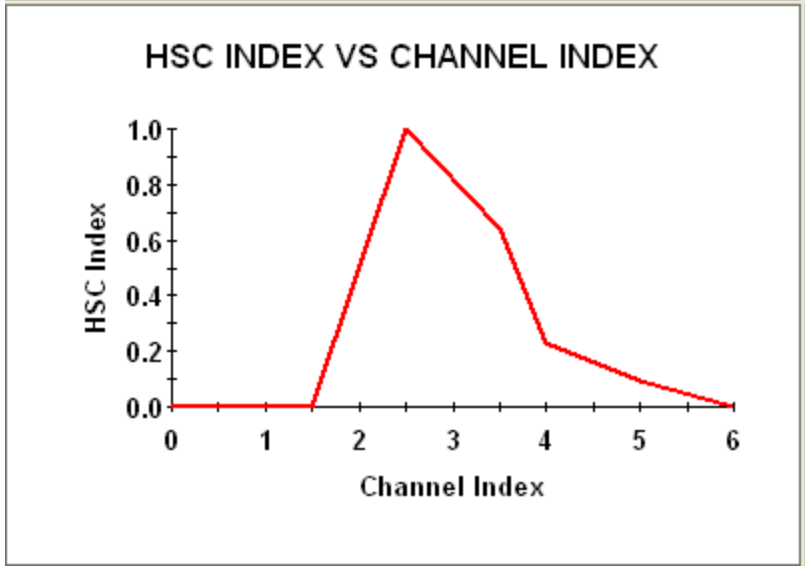




Common Carp - Adult

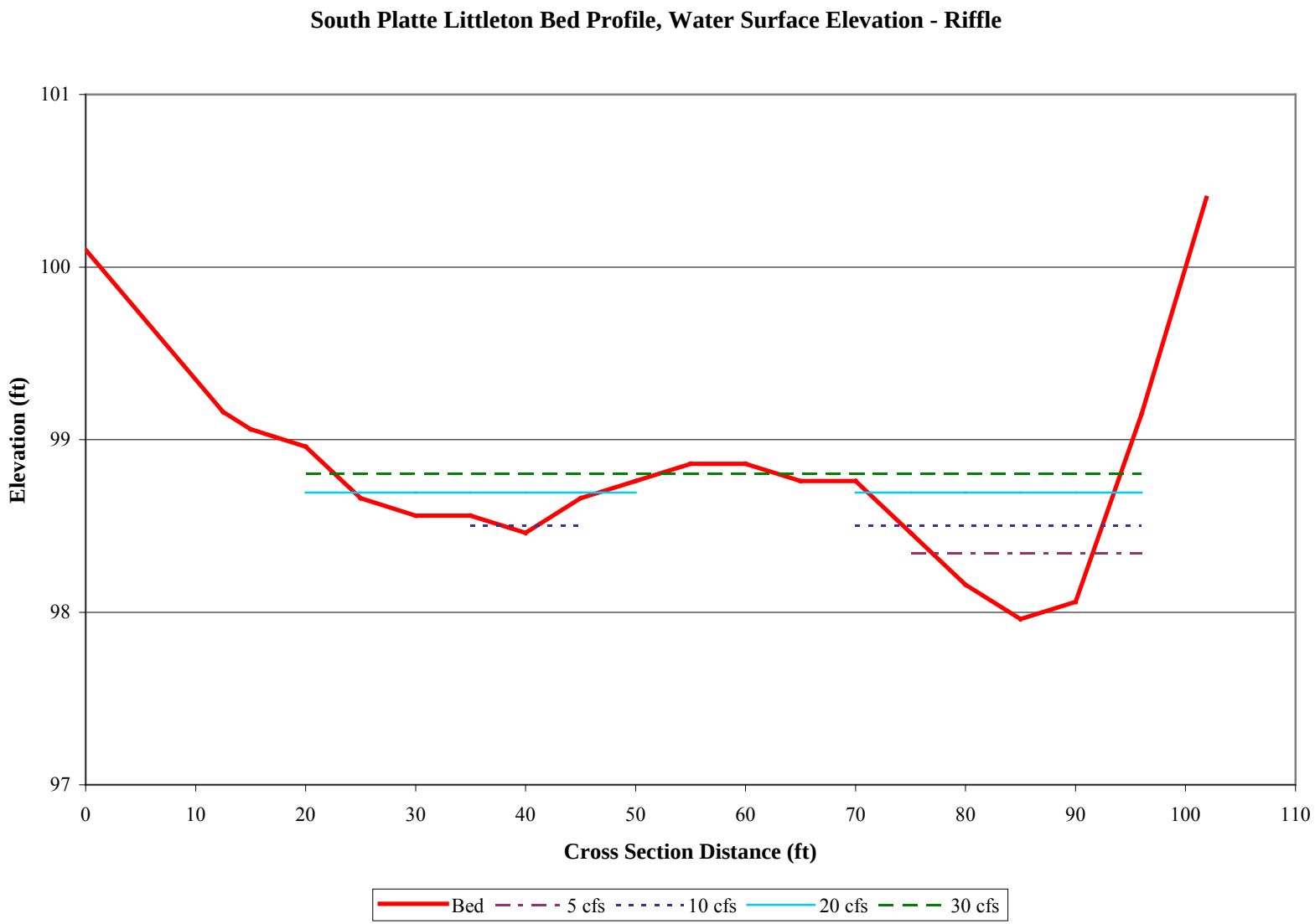






Attachment B

Cross Section Flow and Wetted Perimeter Analysis

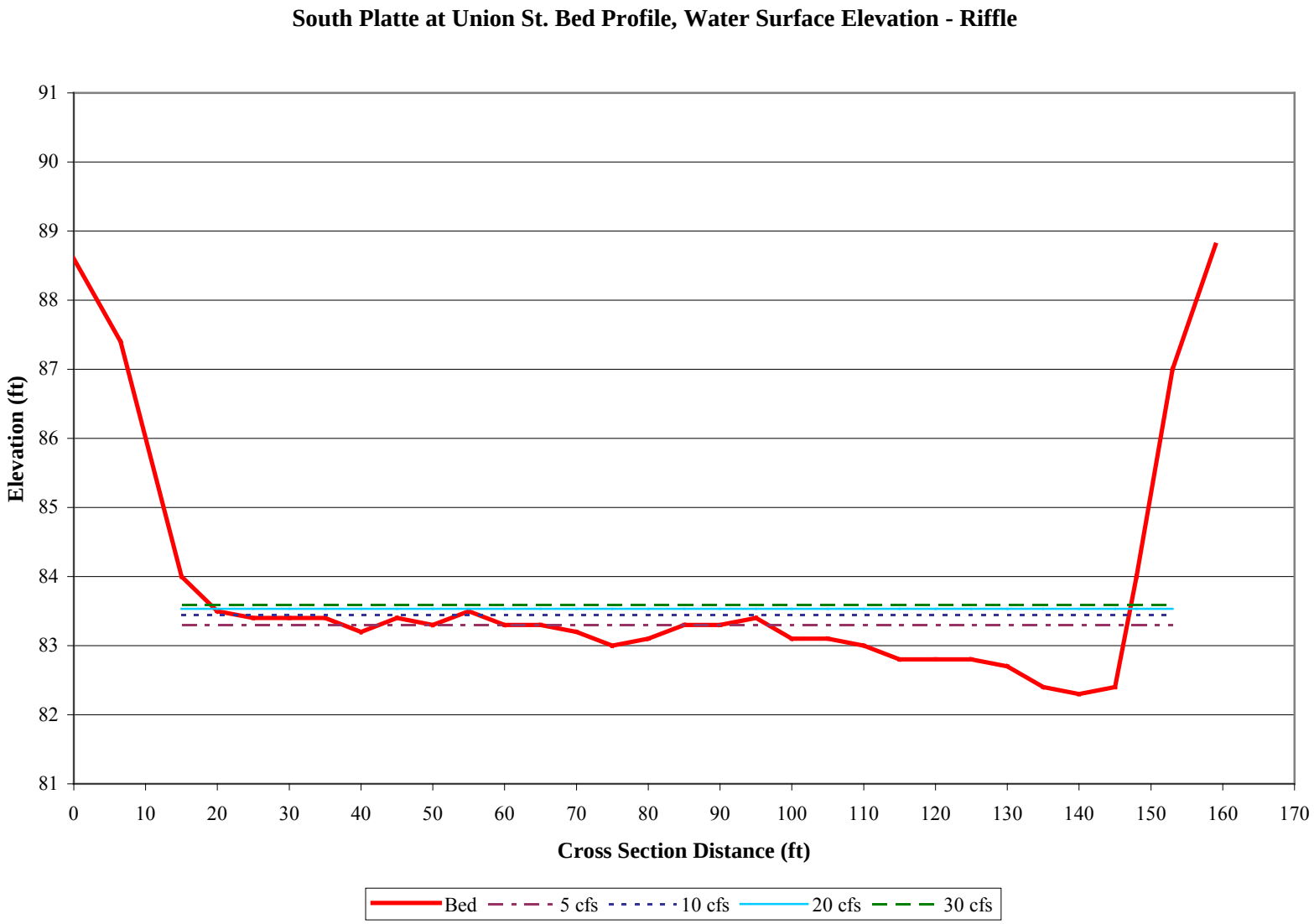


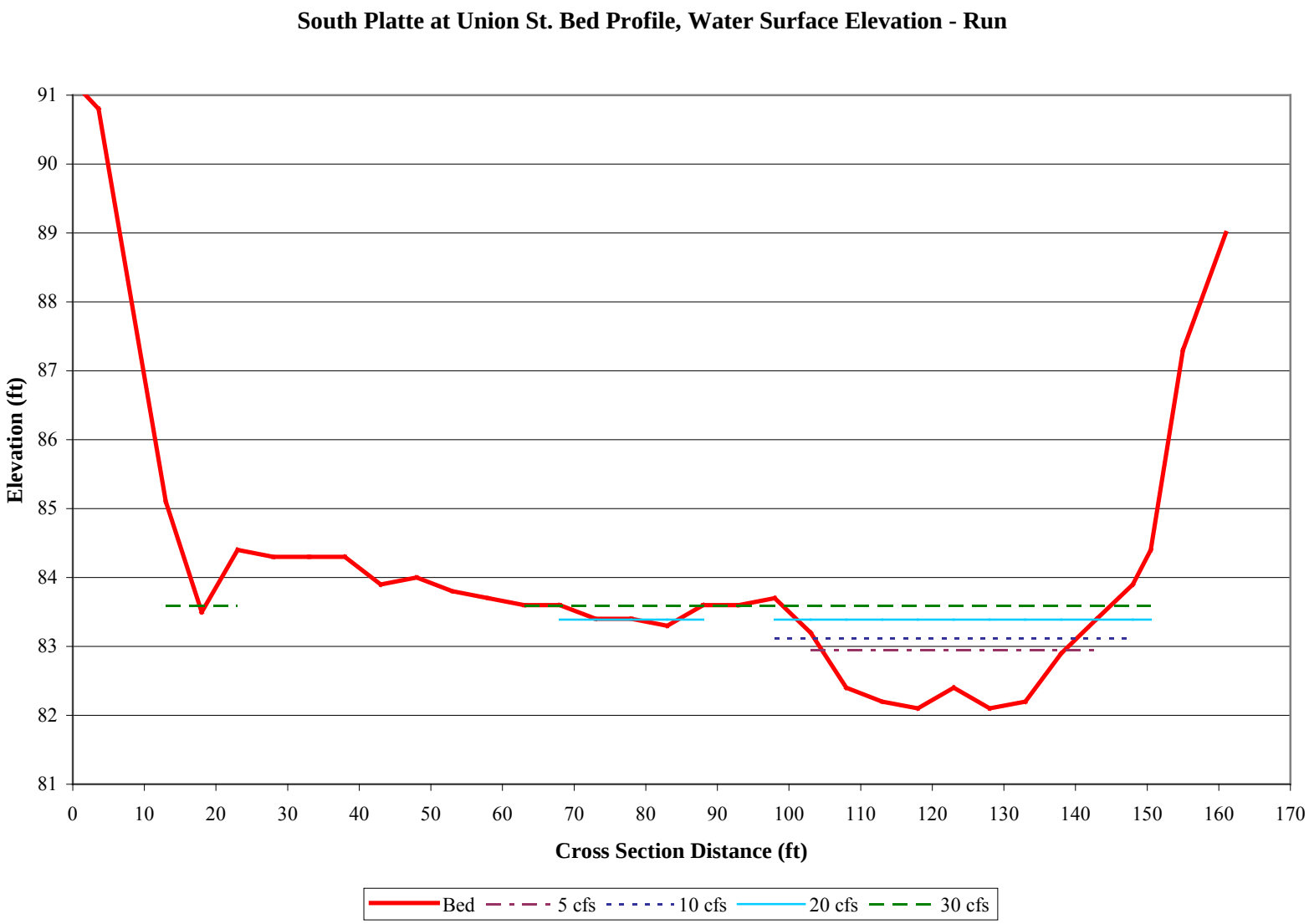
November 17, 2006

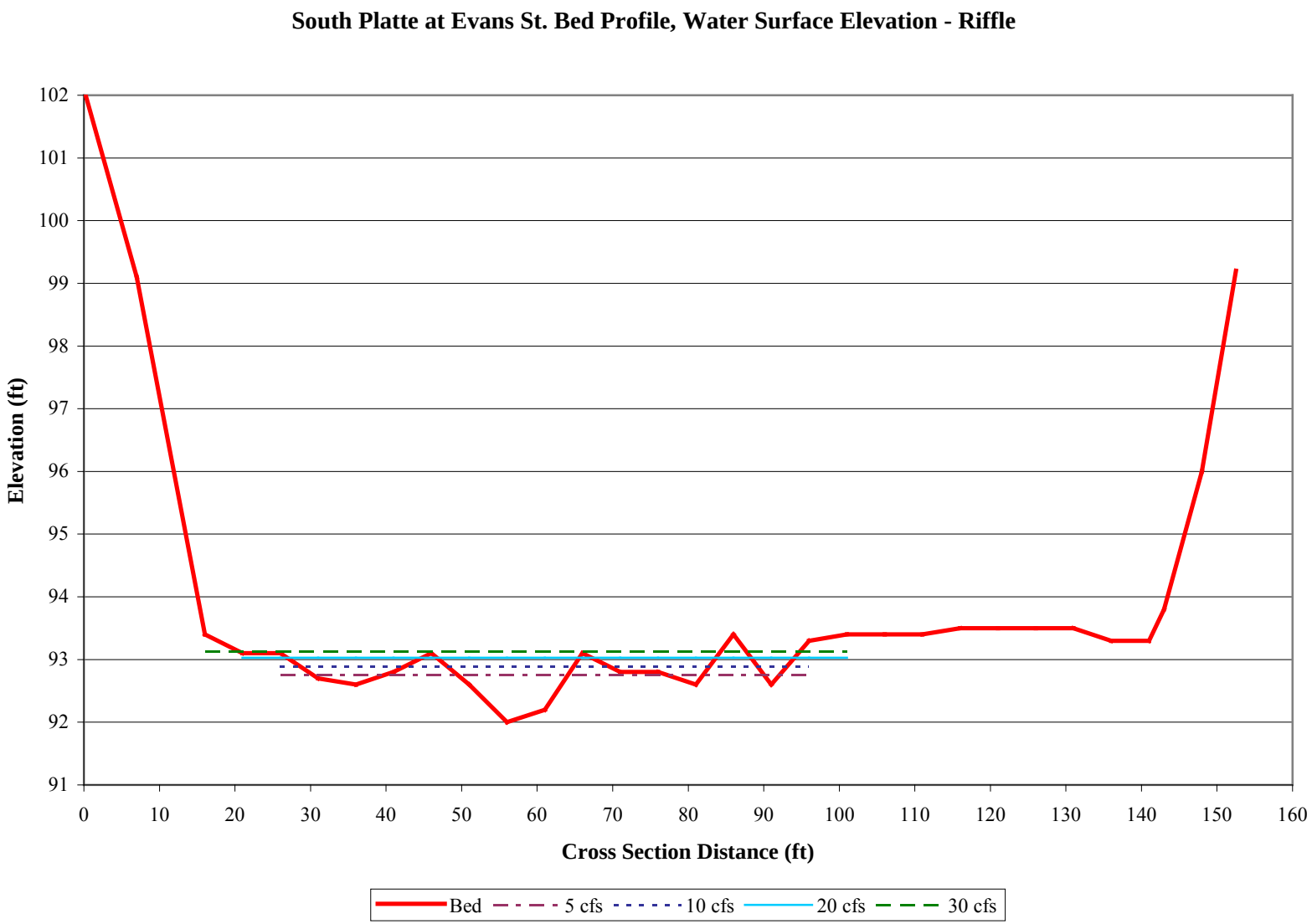
Preliminary Results – Subject to Revision

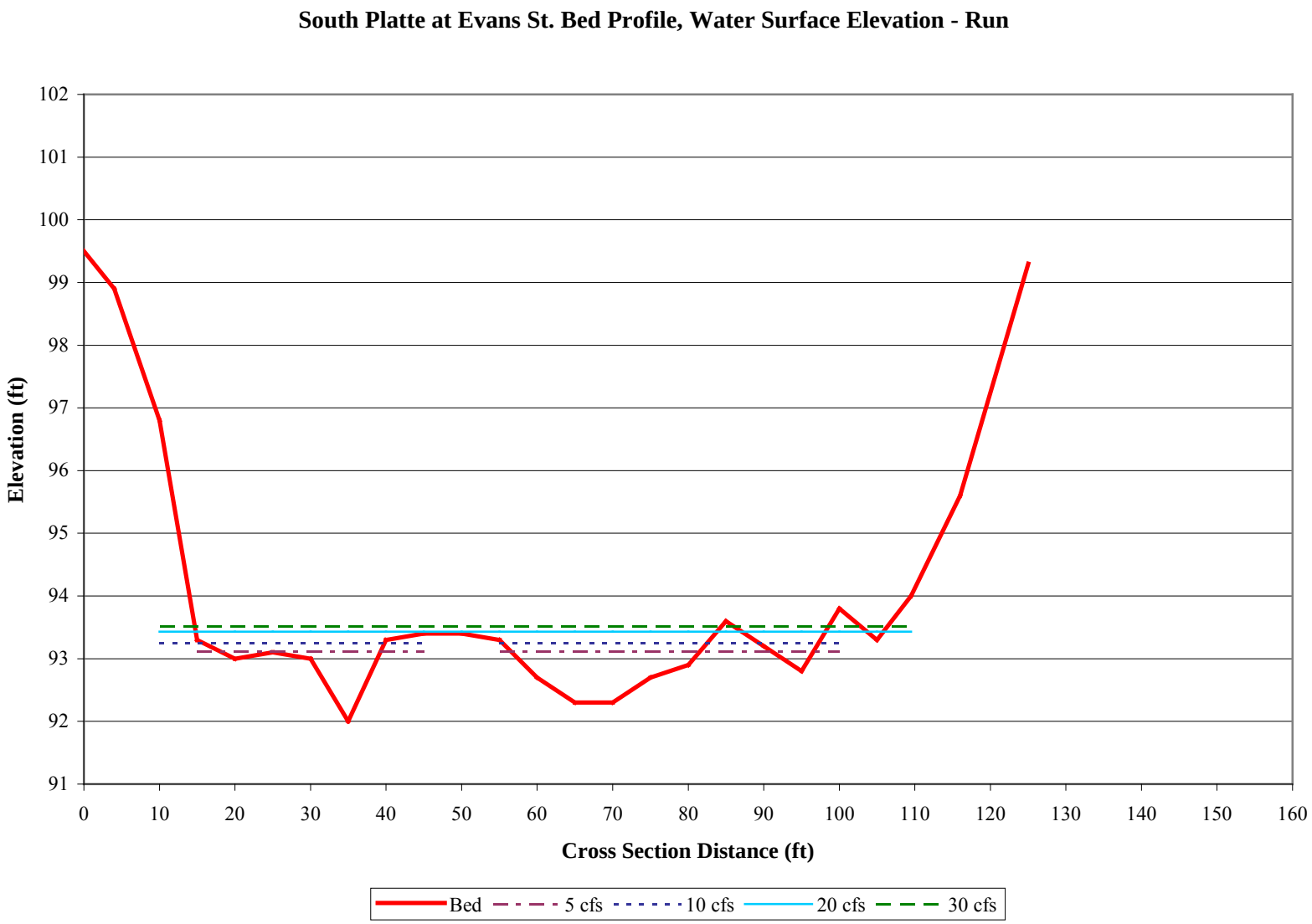
November 17, 2006

Preliminary Results – Subject to Revision


South Platte at Union St. Bed Profile, Water Surface Elevation - Riffle
Elevation (ft)
91
90
89
88
87
86
85
84
83
82
81
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Cross Section Distance (ft)
Bed
5 cfs
10 cfs
20 cfs
30 cfs

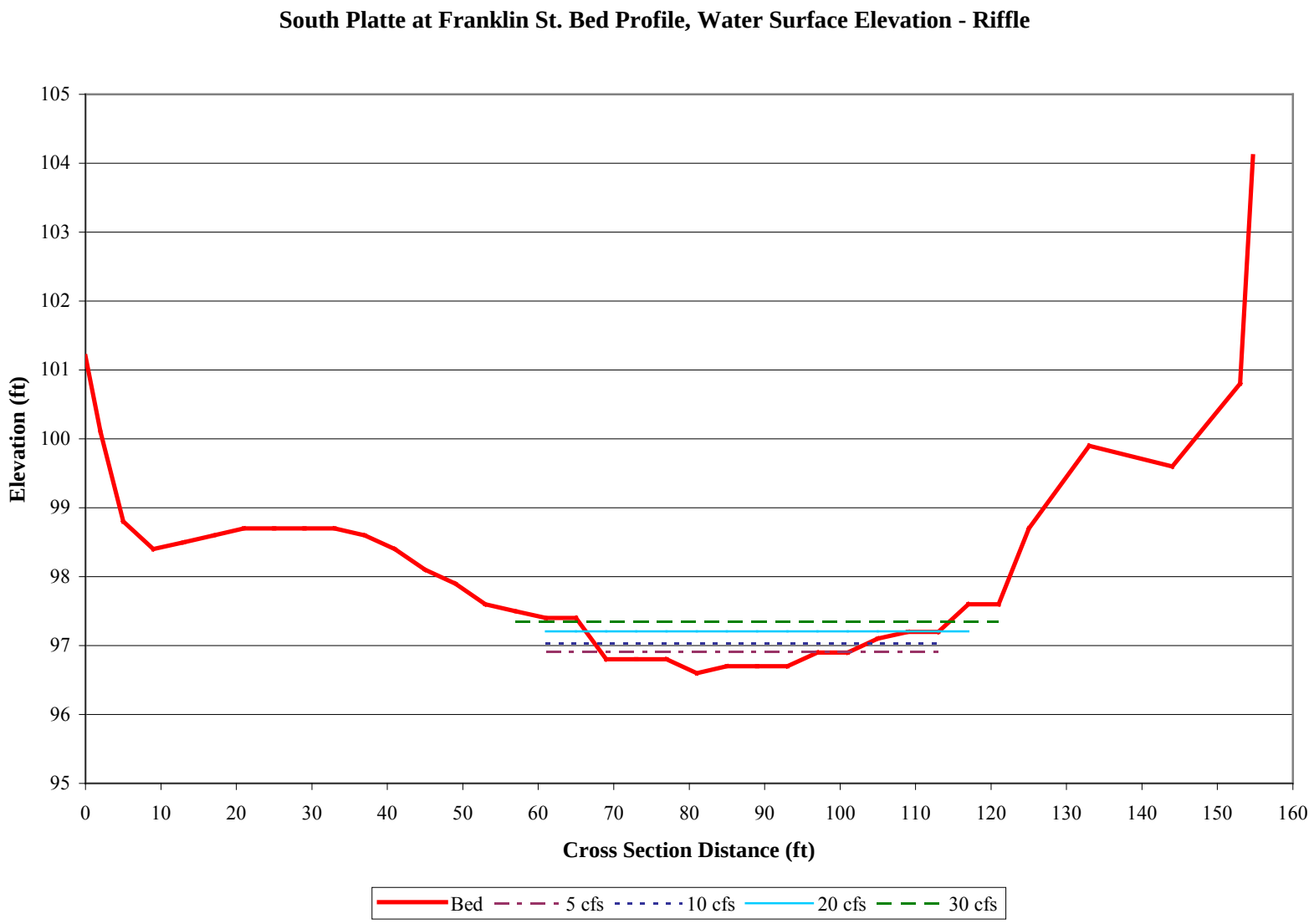

South Platte at Union St. Bed Profile, Water Surface Elevation - Run
Elevation (ft)
91
90
89
88
87
86
85
84
83
82
81
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Cross Section Distance (ft)
Bed
5 cfs
10 cfs
20 cfs
30 cfs


South Platte at Evans St. Bed Profile, Water Surface Elevation - Riffle
Elevation (ft)
102
101
100
99
98
97
96
95
94
93
92
91
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Cross Section Distance (ft)
Bed
5 cfs
10 cfs
20 cfs
30 cfs



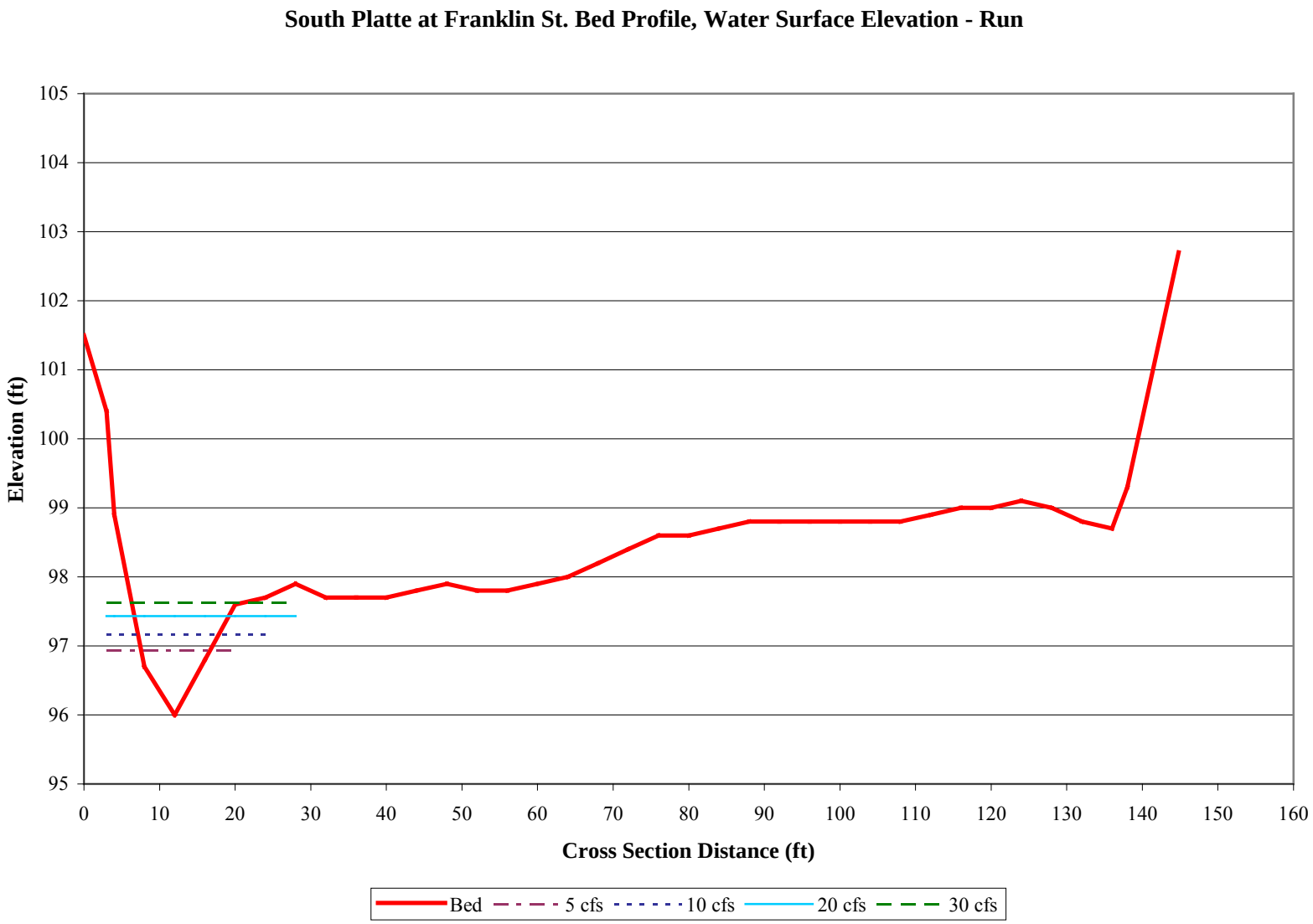
November 17, 2006

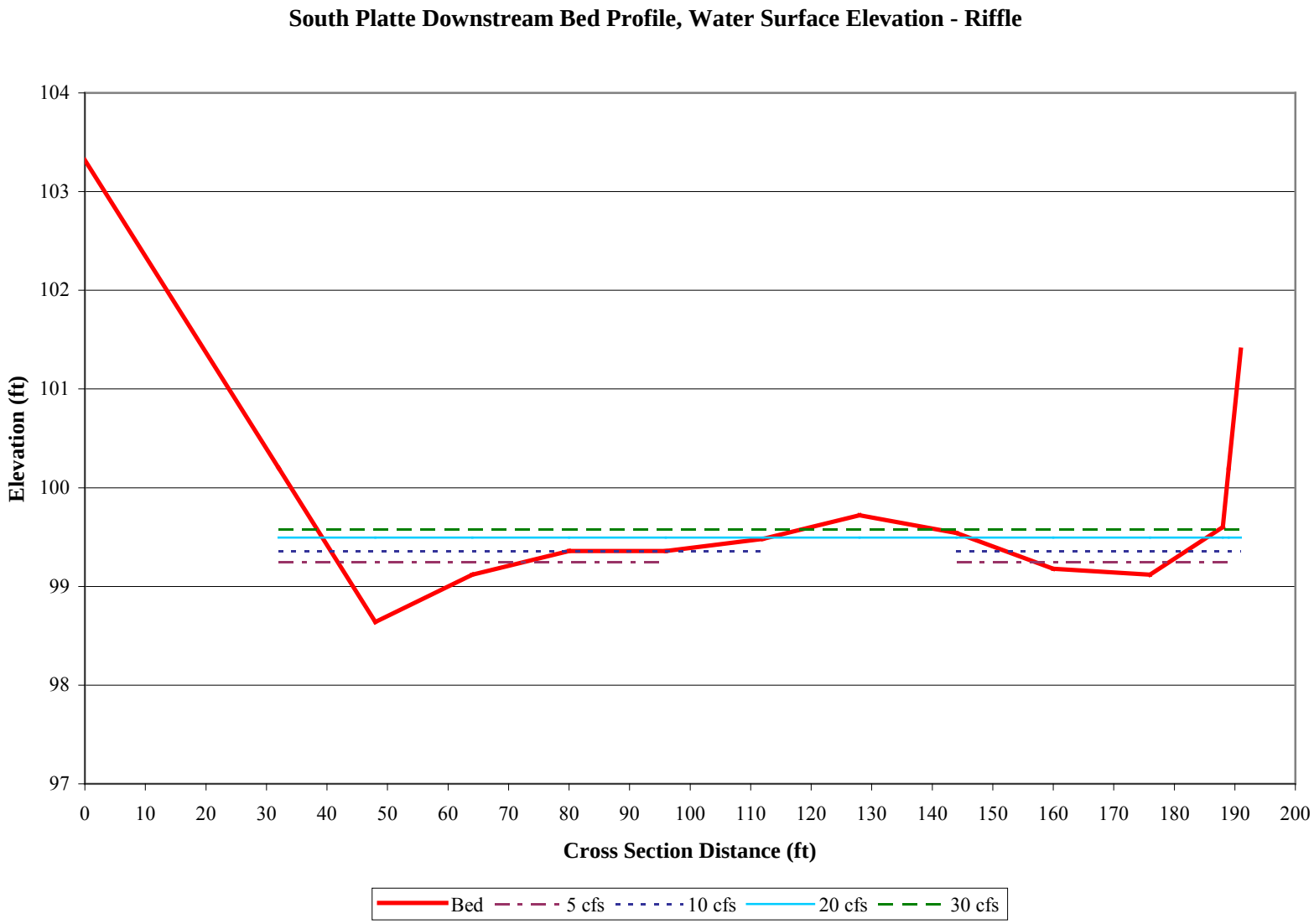
Preliminary Results – Subject to Revision



November 17, 2006

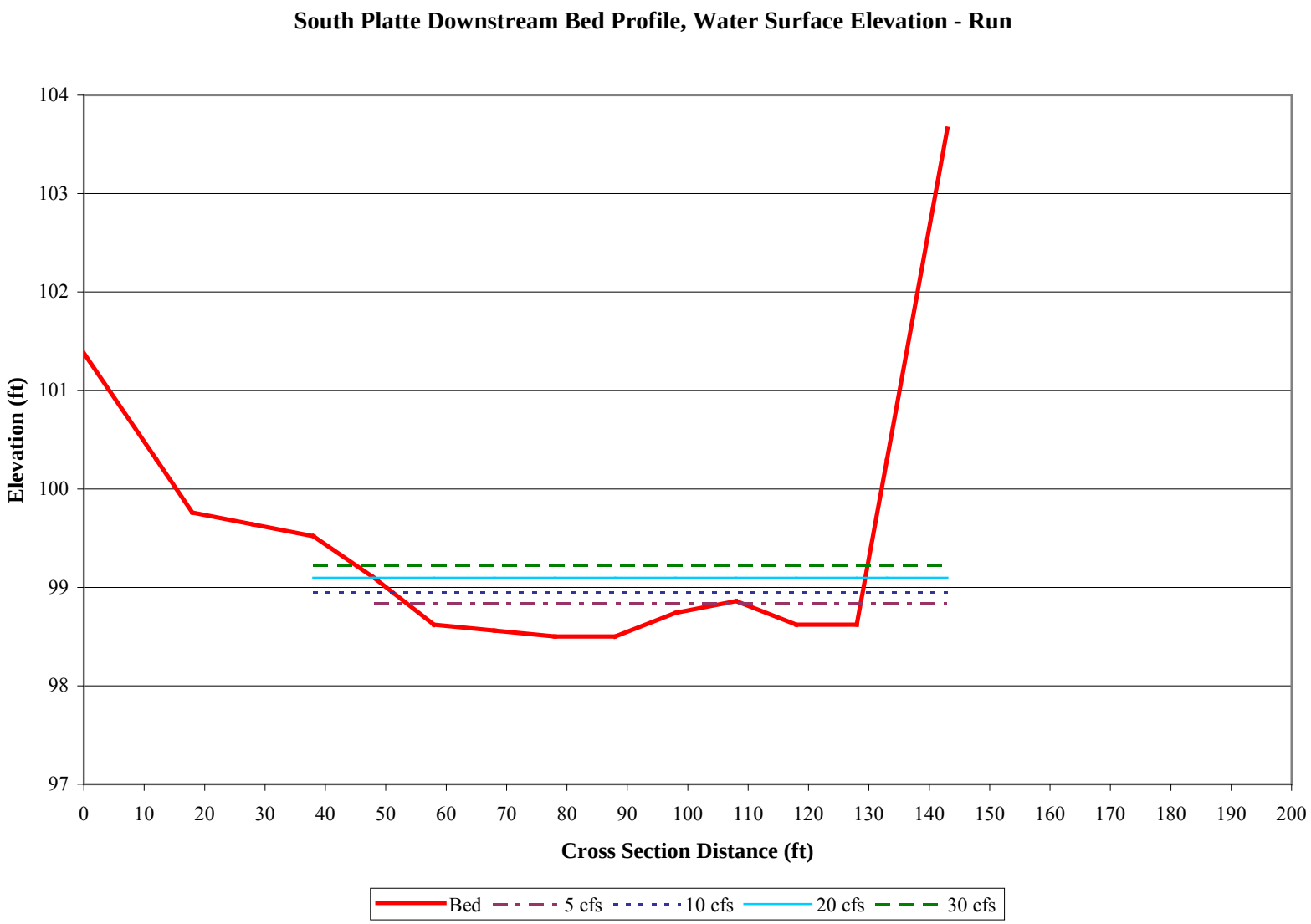
Preliminary Results – Subject to Revision


South Platte at Franklin St. Bed Profile, Water Surface Elevation - Run
Elevation (ft)
105
104
103
102
101
100
99
98
97
96
95
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Cross Section Distance (ft)
Bed
5 cfs
10 cfs
20 cfs
30 cfs



November 17, 2006

Preliminary Results – Subject to Revision

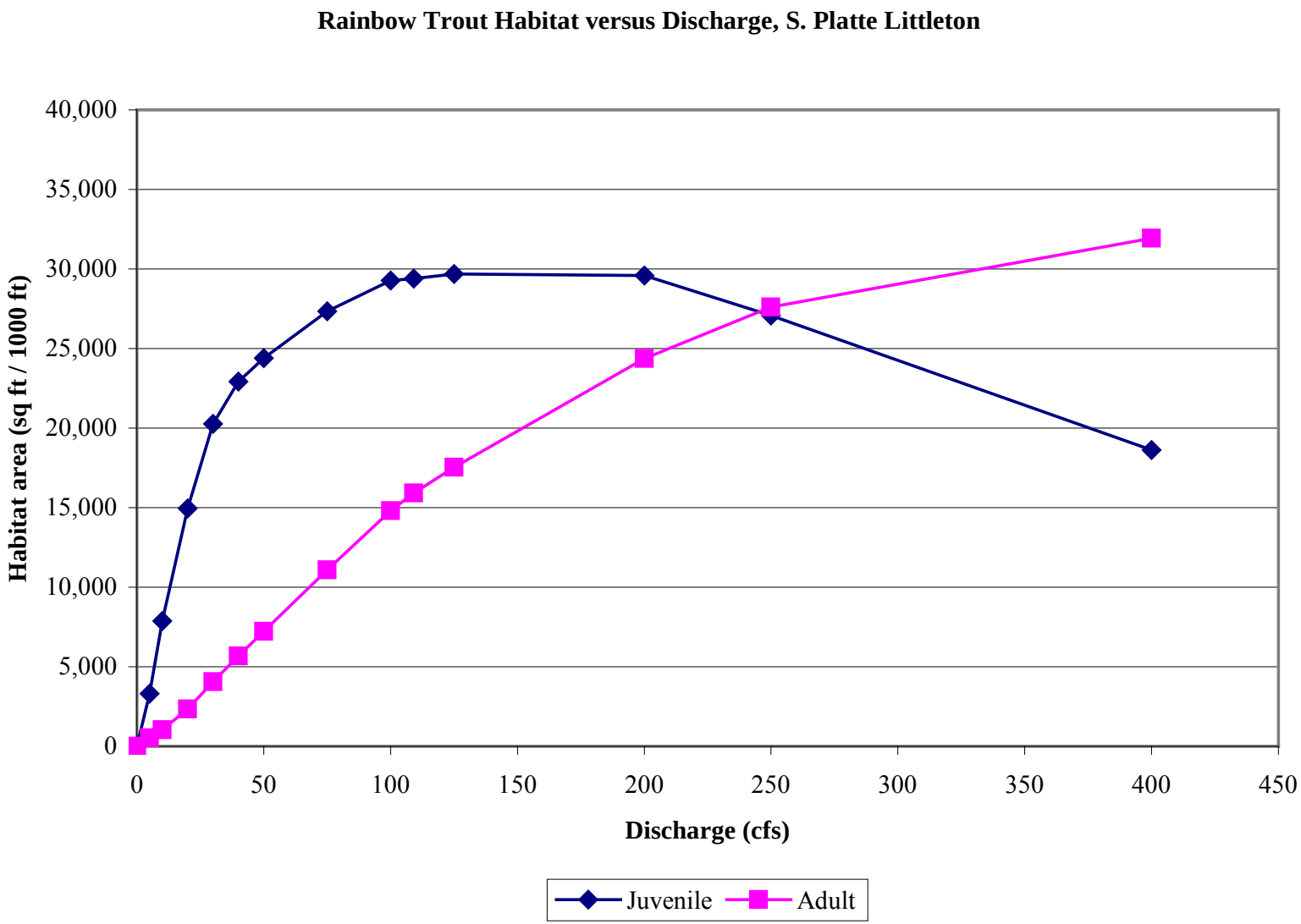

South Platte Downstream Bed Profile, Water Surface Elevation - Run
Elevation (ft)
104
103
102
101
100
99
98
97
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Cross Section Distance (ft)
Bed
5 cfs
10 cfs
20 cfs
30 cfs

Attachment C

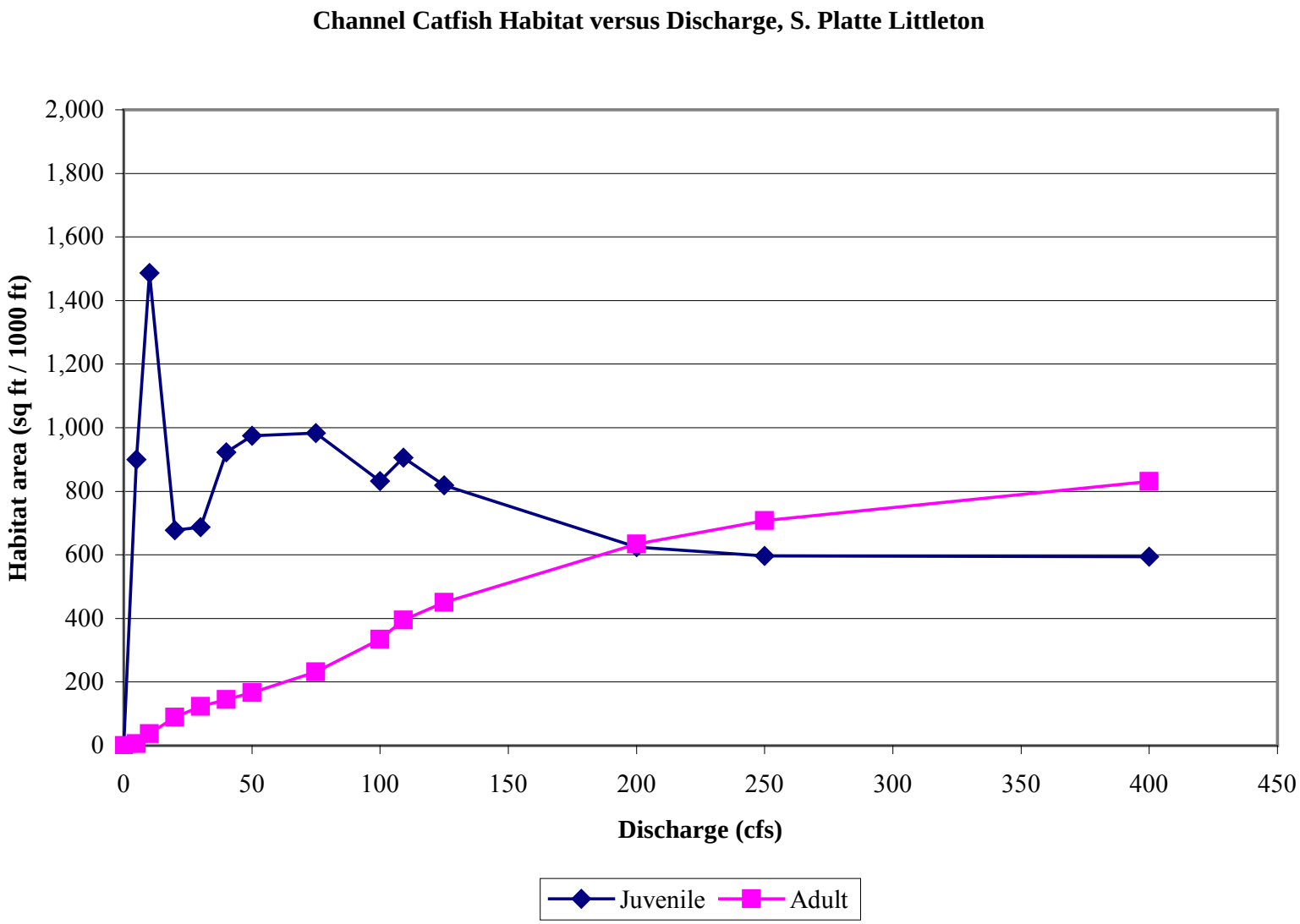
Habitat Flow Relationships

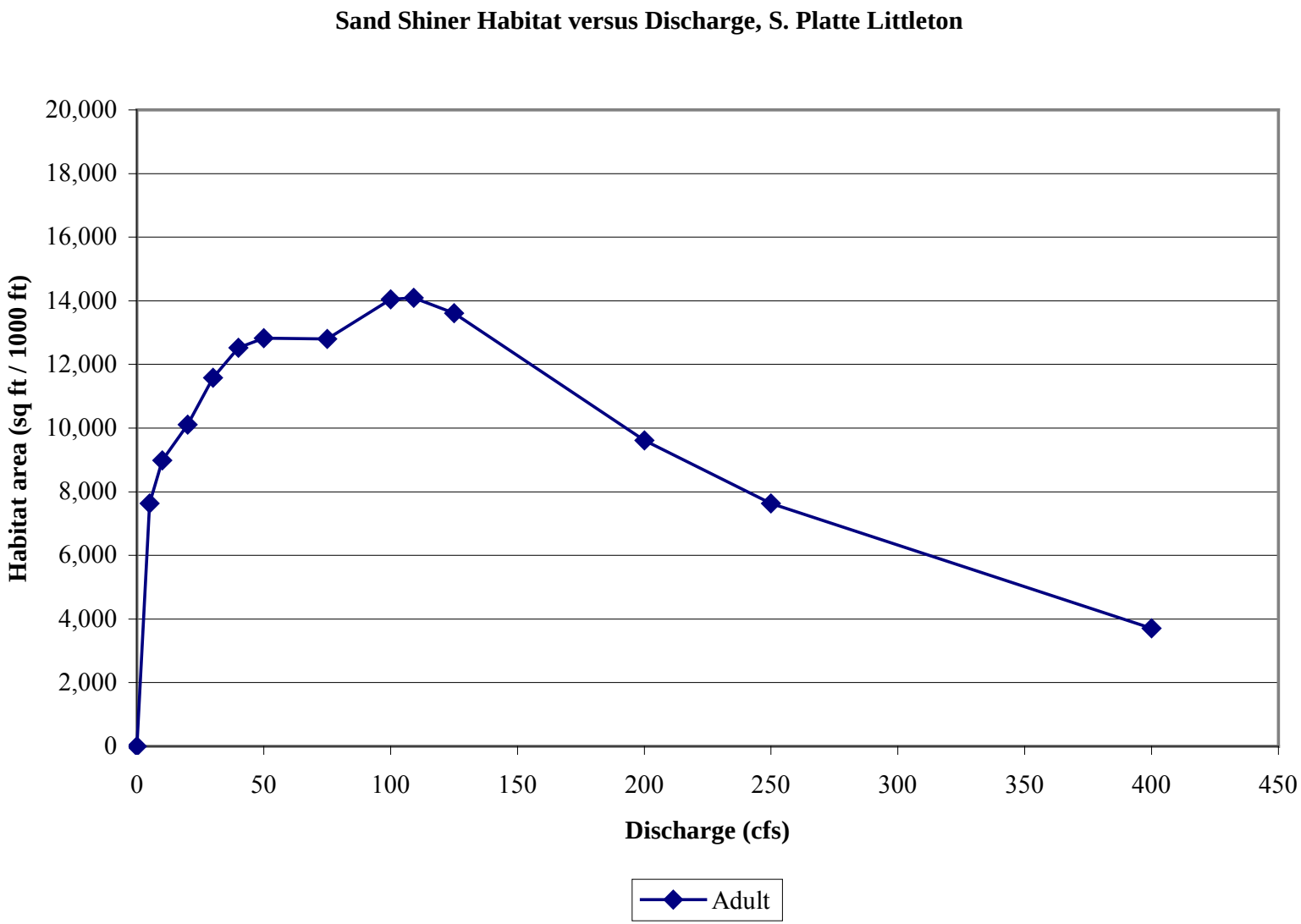
Habitat flow relationships

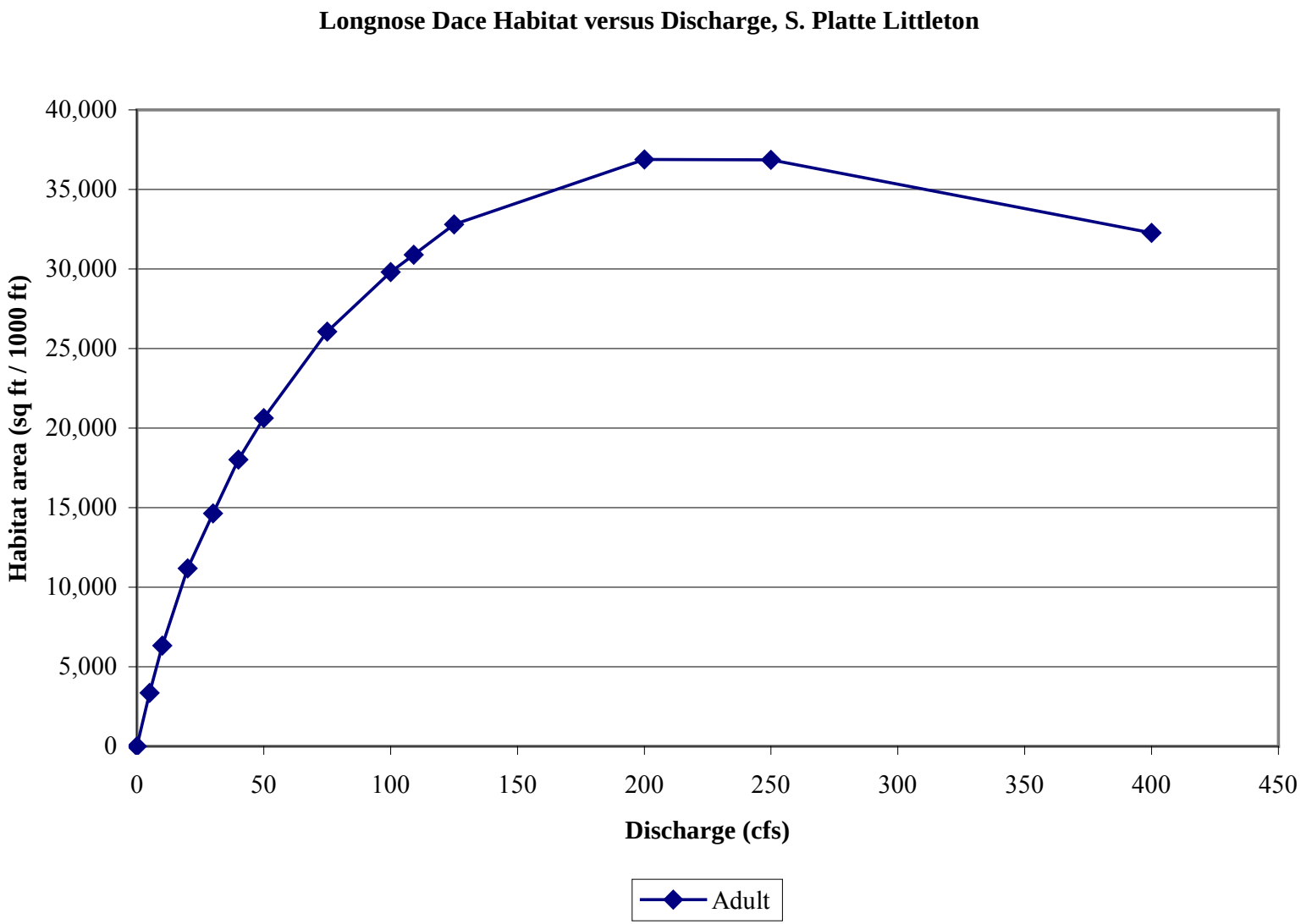
Southern reaches


Rainbow Trout Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult

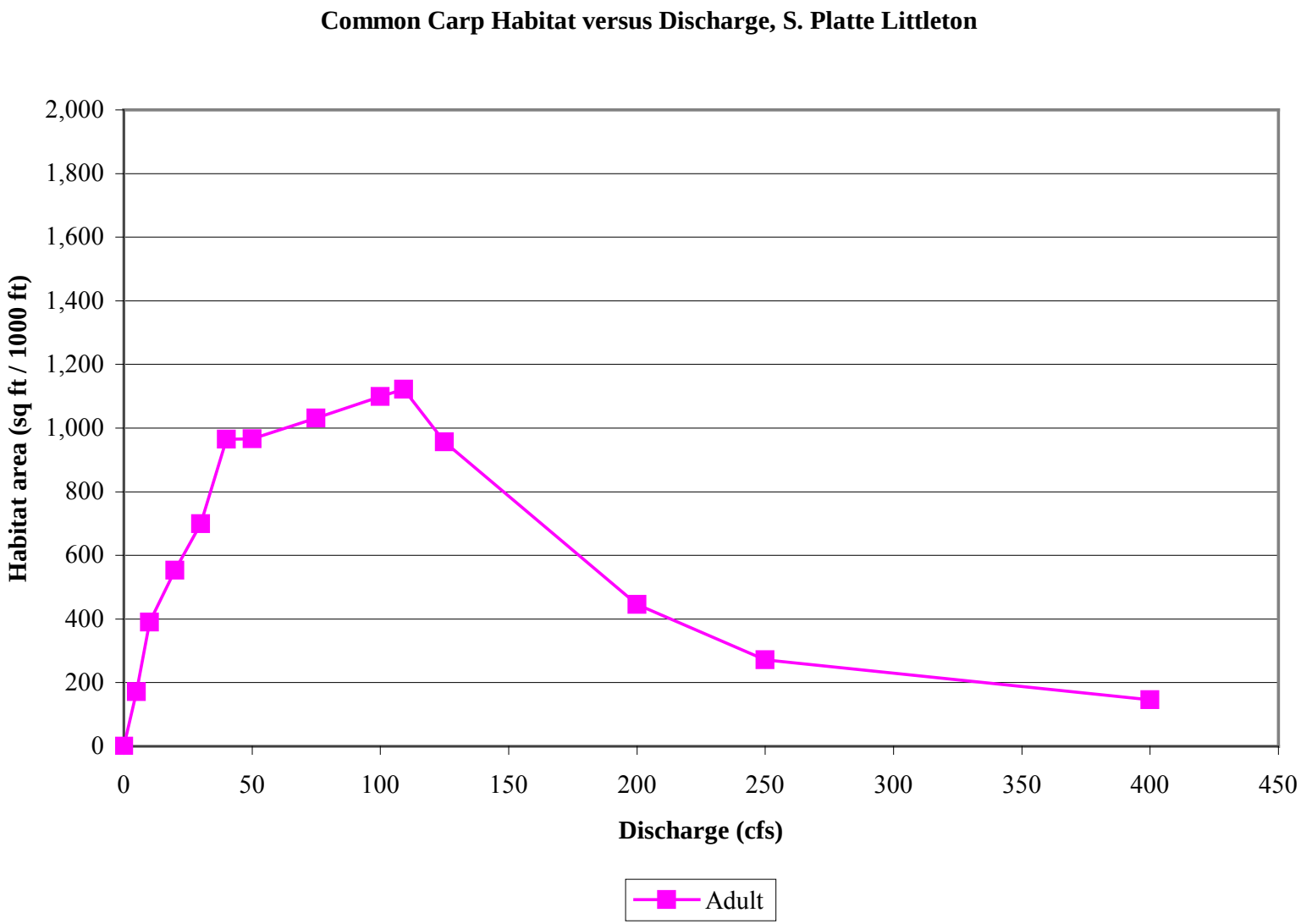
Brown Trout Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult


Channel Catfish Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult


Sand Shiner Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

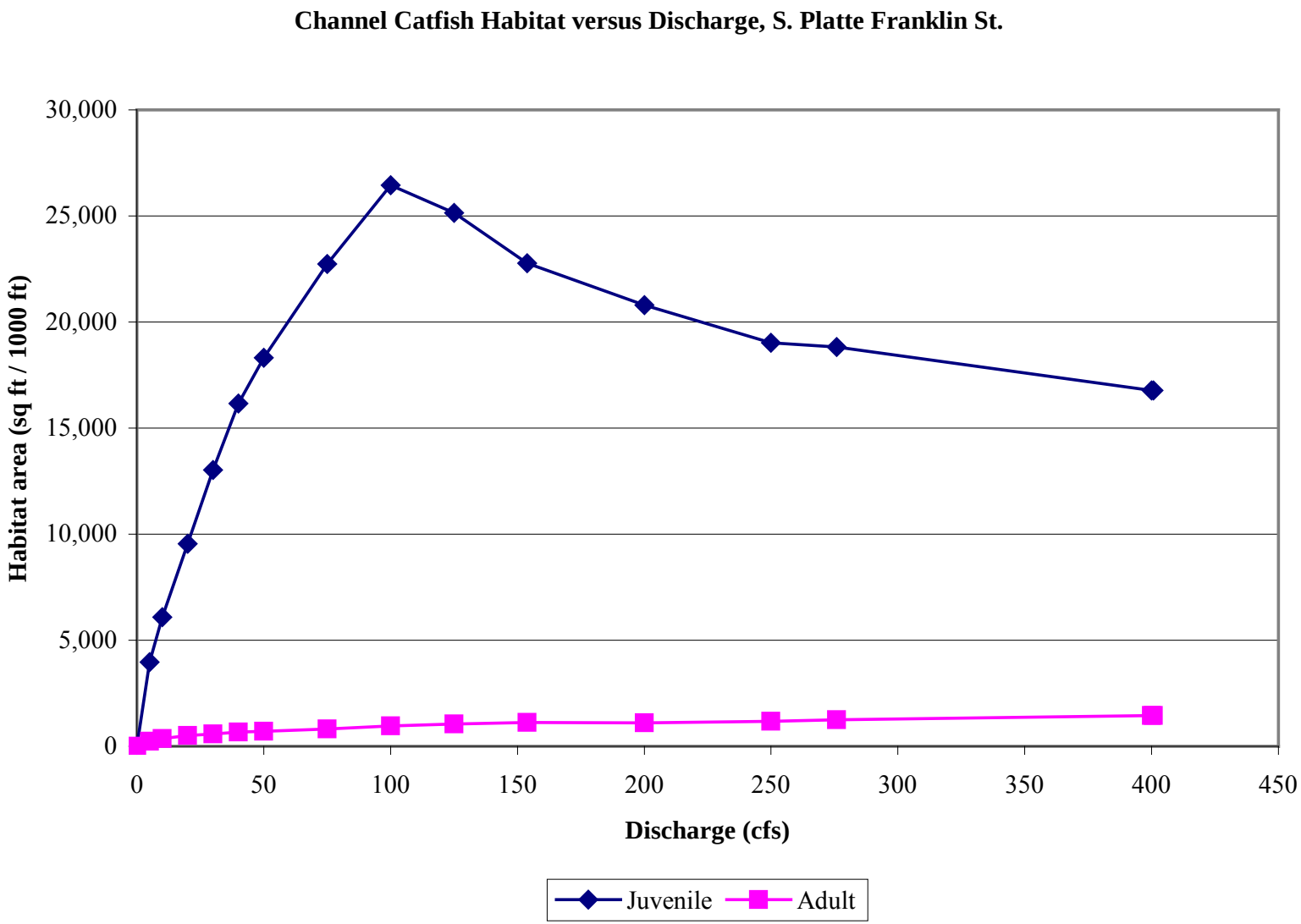

Longnose Dace Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

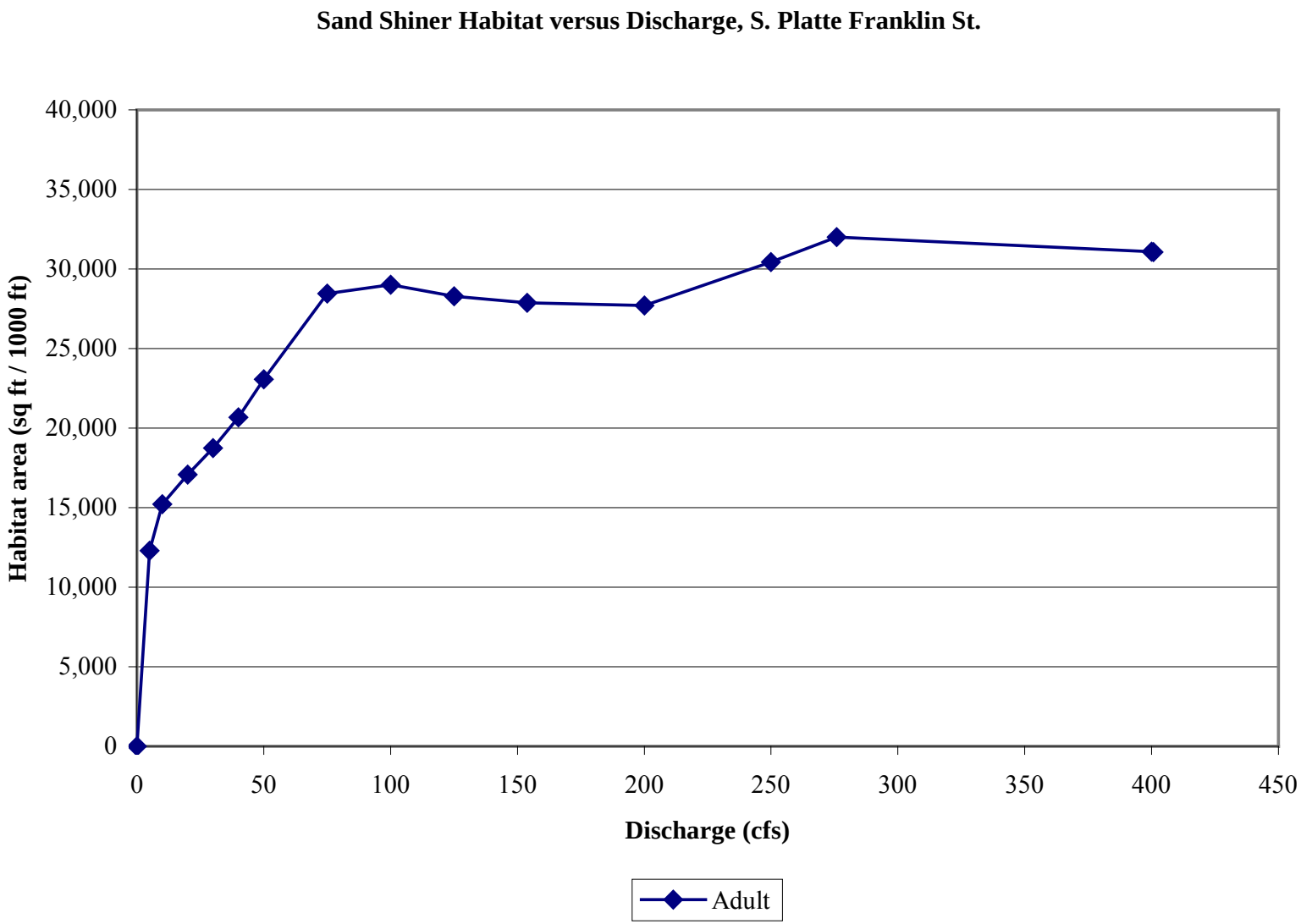
White Sucker Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult

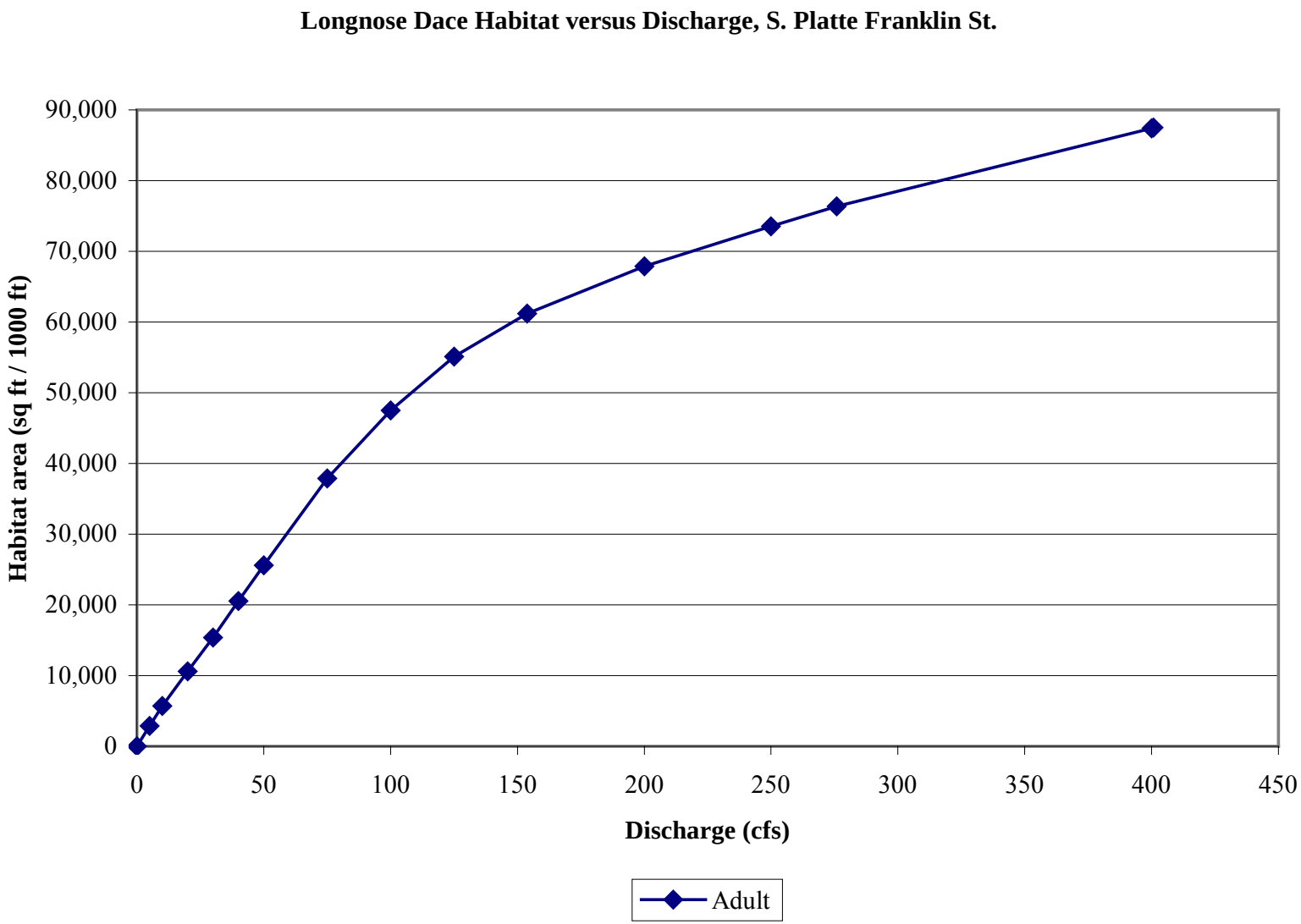

Common Carp Habitat versus Discharge, S. Platte Littleton
Habitat area (sq ft / 1000 ft)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

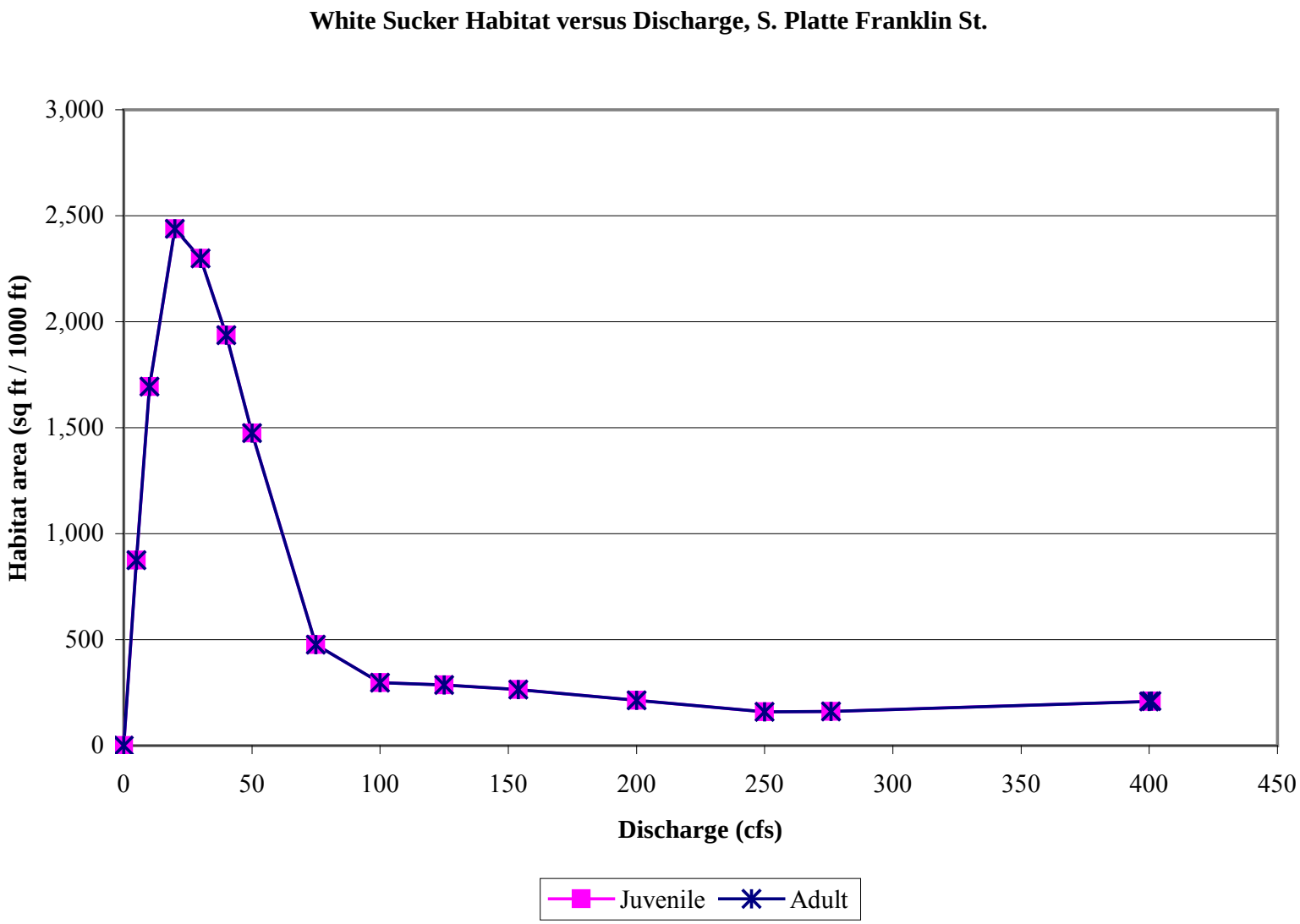
Habitat flow relationships

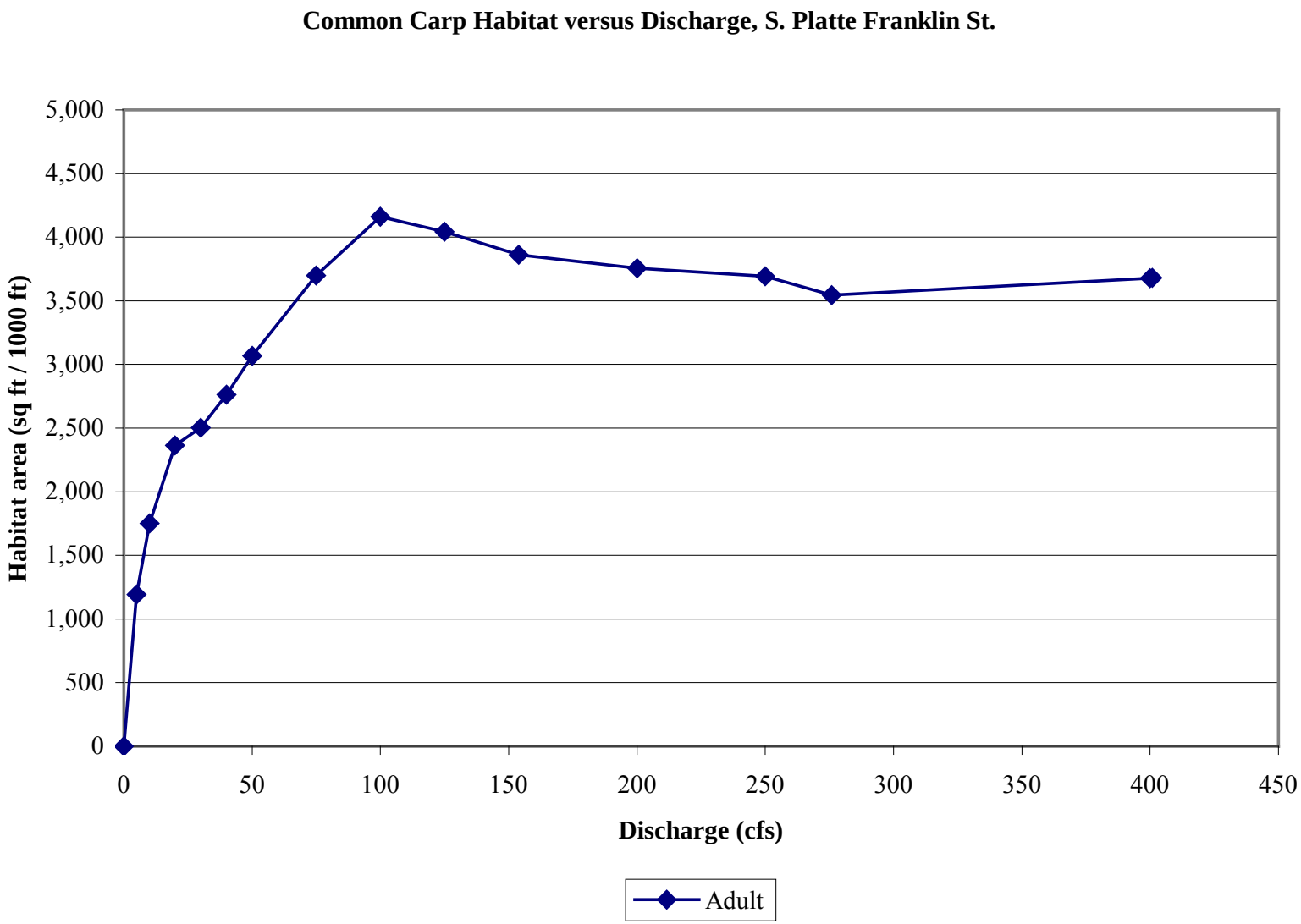
Middle reaches


Channel Catfish Habitat versus Discharge, S. Platte Franklin St.
Habitat area (sq ft / 1000 ft)
30,000
25,000
20,000
15,000
10,000
5,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult


Sand Shiner Habitat versus Discharge, S. Platte Franklin St.
Habitat area (sq ft / 1000 ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

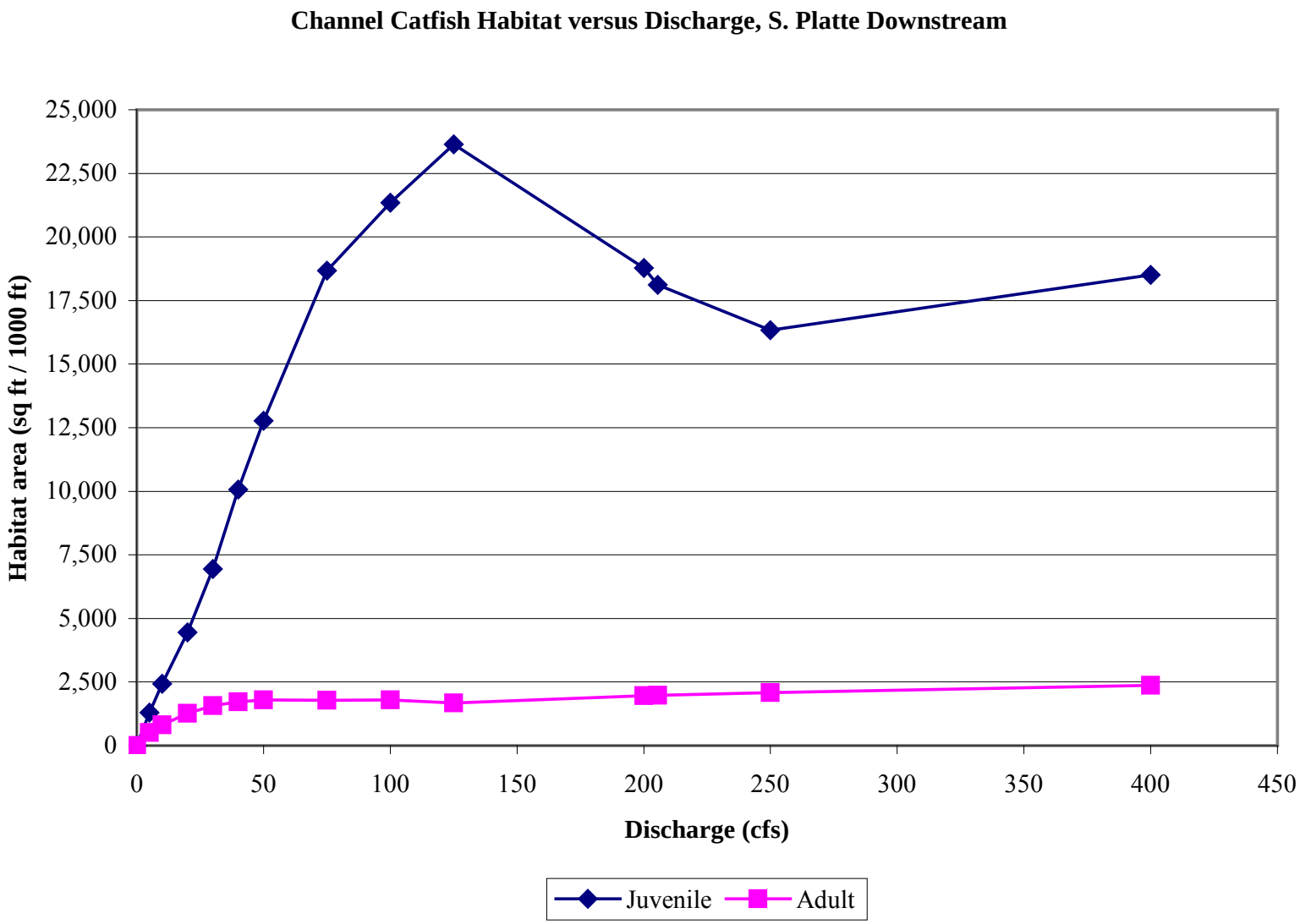

Longnose Dace Habitat versus Discharge, S. Platte Franklin St.
Habitat area (sq ft / 1000 ft)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

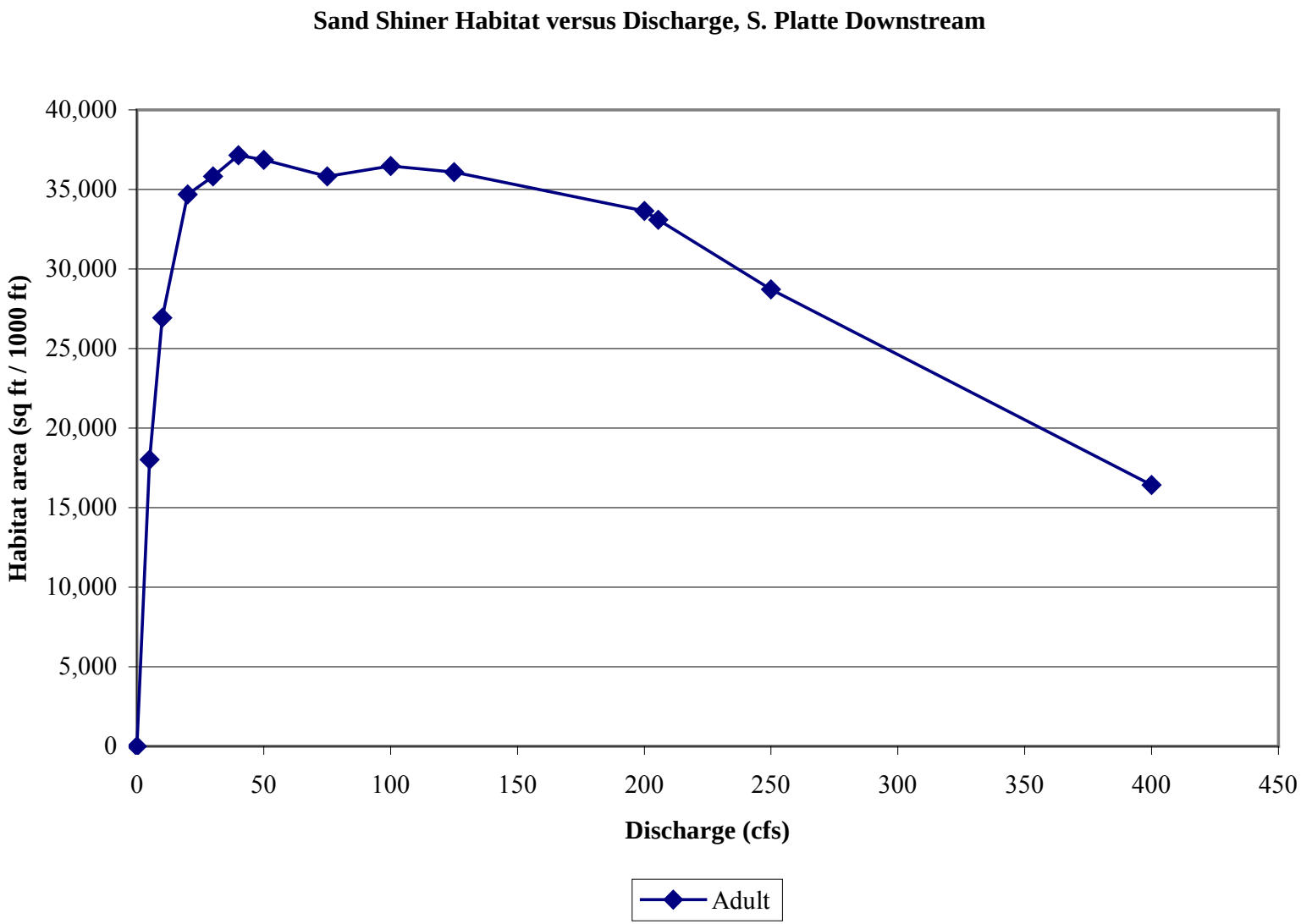

White Sucker Habitat versus Discharge, S. Platte Franklin St.
Habitat area (sq ft / 1000 ft)
3,000
2,500
2,000
1,500
1,000
500
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult

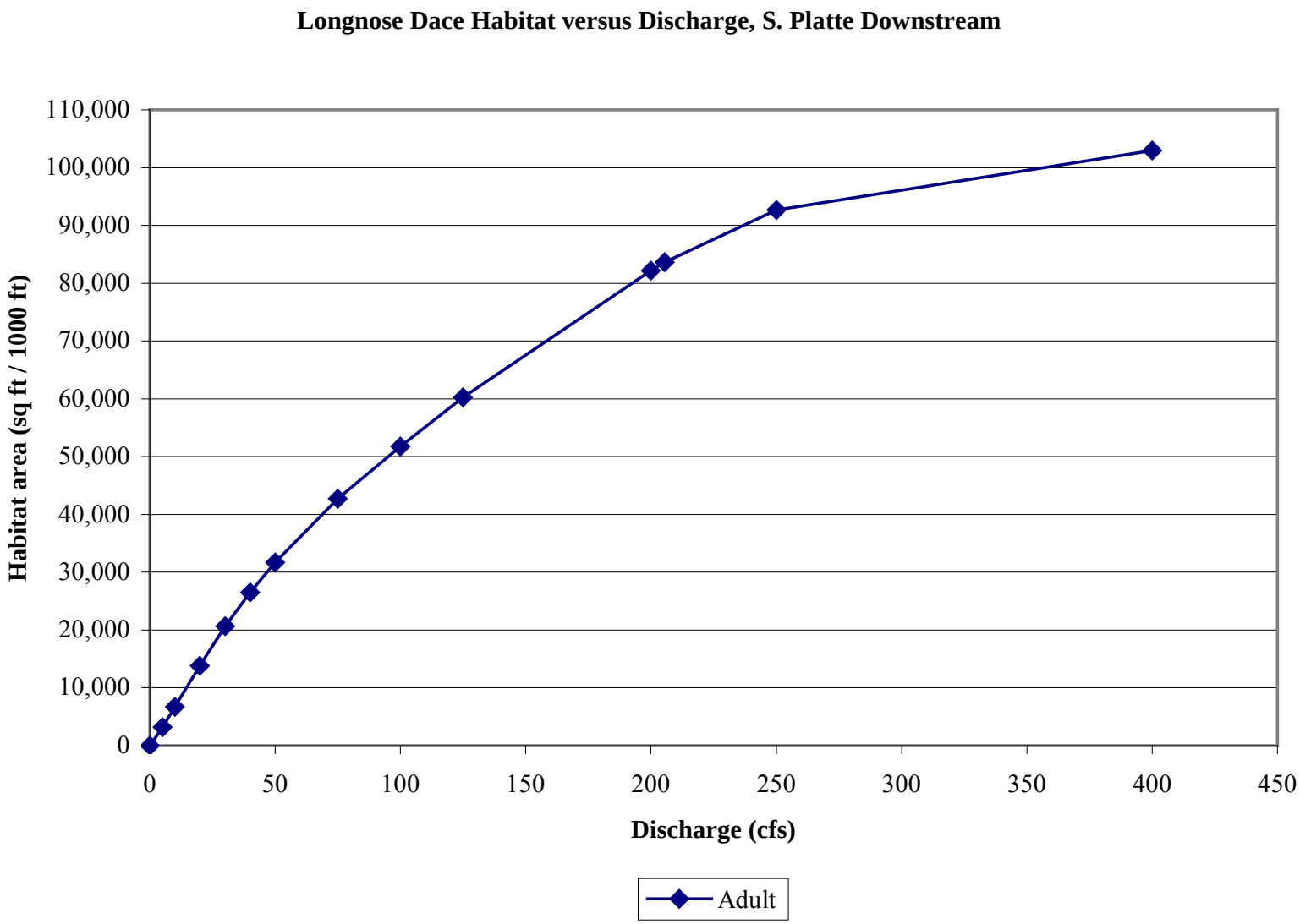

Common Carp Habitat versus Discharge, S. Platte Franklin St.
Habitat area (sq ft / 1000 ft)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

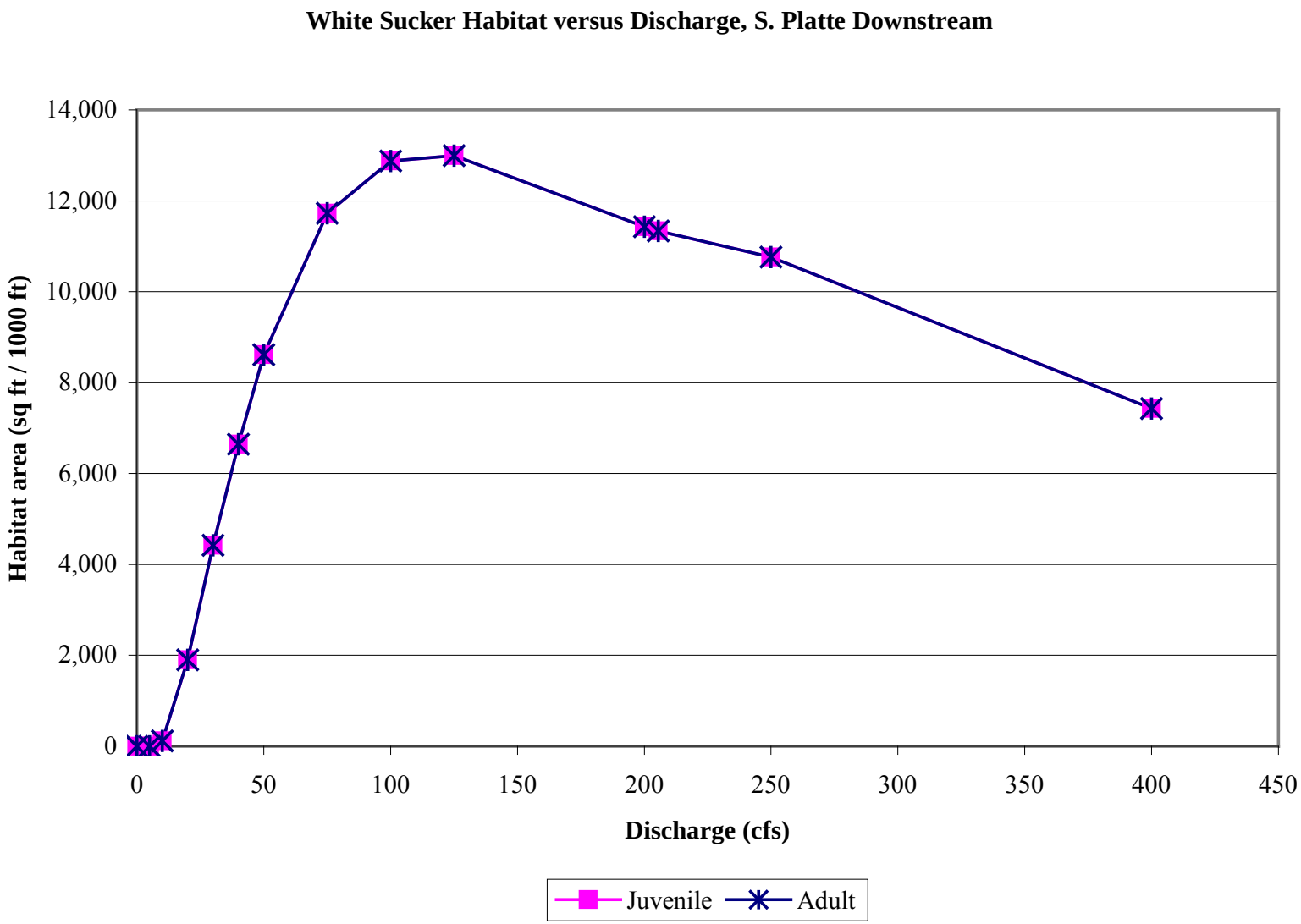
Habitat flow relationships

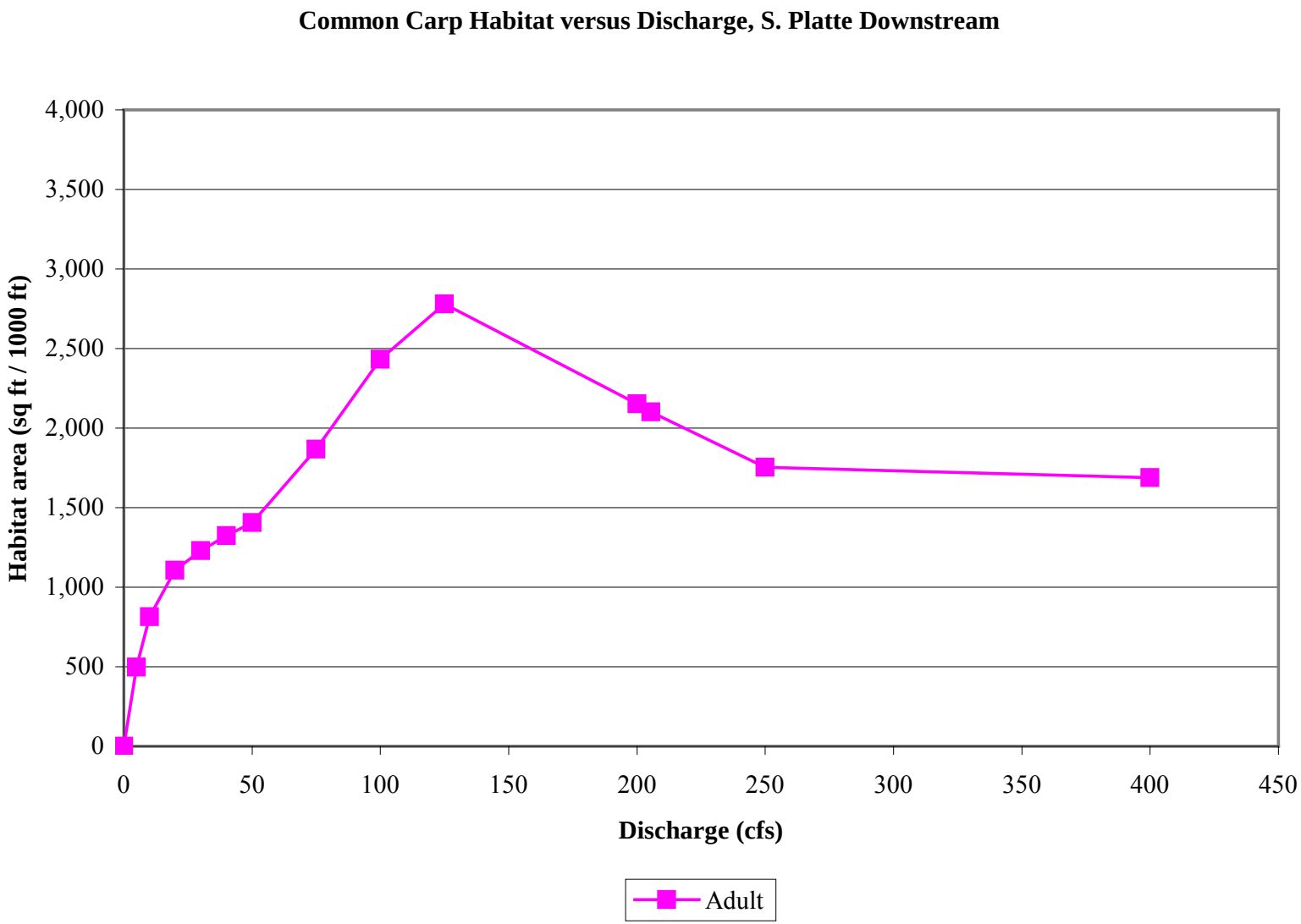
Northeastern reaches


Channel Catfish Habitat versus Discharge, S. Platte Downstream
Habitat area (sq ft / 1000 ft)
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult


Sand Shiner Habitat versus Discharge, S. Platte Downstream
Habitat area (sq ft / 1000 ft)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult


Longnose Dace Habitat versus Discharge, S. Platte Downstream
Habitat area (sq ft / 1000 ft)
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult


White Sucker Habitat versus Discharge, S. Platte Downstream
Habitat area (sq ft / 1000 ft)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Juvenile
Adult


Common Carp Habitat versus Discharge, S. Platte Downstream
Habitat area (sq ft / 1000 ft)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
50
100
150
200
250
300
350
400
450
Discharge (cfs)
Adult

Attachment D

Summary of Wet and Average Year Habitat Area Change for Fish Species of Interest

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Table 1. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), rainbow trout.

Average change in rainbow trout habitat by month

	Adult		Juvenile	
	Wet	**Average**	**Wet**	**Average**
October	-4.3%	-20.6%	-0.4%	-4.6%
November	-11.8%	27.1%	-1.9%	22.4%
December	6.1%	69.5%	3.9%	67.1%
January	14.8%	44.1%	7.9%	36.2%
February	13.1%	46.8%	5.7%	34.8%
March	6.4%	-2.8%	0.0%	1.1%
April	-11.5%	-8.3%	-5.4%	0.0%
May	-16.4%	-7.5%	-16.4%	5.4%
June	-4.6%	-4.3%	-4.6%	-1.2%
July	1.6%	13.5%	1.6%	-2.4%
August	1.3%	2.5%	-1.2%	-1.1%
September	1.8%	-3.6%	0.7%	-0.4%

Table 2. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), brown trout.

Average change in brown trout habitat by month

	Adult		Juvenile	
	Wet	**Average**	**Wet**	**Average**
October	-3.3%	-18.5%	-0.3%	-3.8%
November	-10.1%	29.8%	-1.5%	22.5%
December	6.6%	77.5%	4.3%	66.2%
January	15.8%	51.4%	8.9%	37.8%
February	13.6%	52.7%	6.5%	37.1%
March	6.2%	-1.2%	0.0%	1.6%
April	-10.0%	-6.1%	-5.5%	-0.3%
May	-16.4%	-4.6%	-16.4%	4.7%
June	-4.6%	-3.5%	-4.6%	-1.7%
July	1.6%	10.9%	1.6%	-2.1%
August	0.9%	2.0%	-0.8%	-1.0%
September	1.7%	-2.8%	0.5%	-0.2%

Table 3. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), longnose dace.

Average change in longnose dace habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			-1.8%	-10.0%
November			-5.2%	21.7%
December			4.6%	60.7%
January			8.8%	32.7%
February			7.9%	32.6%
March			0.0%	0.2%
April			-7.2%	-3.3%
May			-16.4%	0.5%
June			-4.6%	-2.4%
July			1.6%	4.6%
August			0.1%	0.7%
September			1.3%	-1.2%

Table 4. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), sand shiner.

Average change in sand shiner habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			0.4%	-1.4%
November			-0.5%	10.7%
December			2.1%	26.2%
January			4.1%	9.8%
February			2.9%	12.3%
March			0.0%	-0.3%
April			-4.4%	4.0%
May			-16.4%	12.5%
June			-4.6%	-0.2%
July			1.6%	-22.0%
August			-3.7%	-5.9%
September			0.8%	-0.6%

Table 5. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), channel catfish.

Average change in channel catfish habitat by month

	Juvenile		Adult	
	Wet	**Average**	**Wet**	**Average**
October	0.8%	-0.4%	-6.4%	-16.6%
November	0.8%	6.2%	-13.0%	27.6%
December	3.6%	-20.3%	4.3%	80.9%
January	5.1%	-55.4%	9.1%	44.0%
February	5.1%	-38.1%	7.8%	40.4%
March	0.0%	4.9%	4.7%	-10.1%
April	-5.6%	2.8%	-12.7%	-12.6%
May	-16.4%	3.0%	-16.4%	-7.3%
June	-4.6%	-3.5%	-4.6%	-4.5%
July	1.6%	-12.5%	1.6%	14.1%
August	0.7%	-2.4%	1.4%	2.7%
September	-0.7%	-0.7%	2.7%	-6.4%

Table 6. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), white sucker.

Average change in white sucker habitat by month

	Juvenile		Adult	
	Wet	**Average**	**Wet**	**Average**
October	-1.0%	-6.9%	-1.0%	-6.9%
November	-3.3%	25.3%	-3.3%	25.3%
December	4.9%	73.7%	4.9%	73.7%
January	10.4%	42.0%	10.4%	42.0%
February	7.4%	41.7%	7.4%	41.7%
March	2.9%	0.4%	0.0%	0.4%
April	-6.3%	-1.3%	-6.3%	-1.3%
May	-16.4%	2.2%	-16.4%	2.2%
June	-4.6%	-2.0%	-4.6%	-2.0%
July	1.6%	1.4%	1.6%	1.4%
August	-0.2%	0.0%	-0.2%	0.0%
September	1.1%	-0.8%	1.1%	-0.8%

Table 7. South Platte at Chatfield current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), common carp.

Average change in common carp habitat by month

	Juvenile		Adult	
	Wet	**Average**	**Wet**	**Average**
October			0.5%	-3.4%
November			0.3%	21.6%
December			5.2%	57.7%
January			9.6%	24.6%
February			6.5%	27.3%
March			0.0%	3.2%
April			-6.6%	9.0%
May			-16.4%	17.8%
June			-4.6%	-2.2%
July			1.6%	-62.4%
August			-3.0%	-16.9%
September			-0.9%	-1.0%

Table 8. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), rainbow trout.

Average change in rainbow trout habitat by month

	Adult		Juvenile	
	Wet	**Average**	**Wet**	**Average**
October	2.5%	-27.5%	0.3%	-10.2%
November	7.8%	39.1%	2.1%	37.0%
December	11.2%	62.3%	4.2%	57.7%
January	14.2%	37.1%	6.4%	30.4%
February	12.9%	21.0%	5.2%	11.2%
March	5.8%	-33.6%	0.0%	-6.7%
April	2.4%	-4.8%	0.9%	-0.6%
May	-0.5%	-2.1%	-0.5%	0.3%
June	-0.4%	-1.4%	-0.4%	1.9%
July	-0.6%	4.5%	-0.3%	-0.4%
August	-2.4%	5.5%	2.2%	1.2%
September	-21.5%	-6.6%	-6.1%	-2.1%

Table 9. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), brown trout.

Average change in brown trout habitat by month

	Adult		Juvenile	
	Wet	Average	Wet	Average
October	2.0%	-29.7%	0.3%	-11.6%
November	7.1%	42.0%	1.8%	37.0%
December	11.1%	70.5%	4.4%	57.6%
January	14.7%	43.8%	7.2%	31.5%
February	13.2%	22.8%	5.8%	12.6%
March	5.6%	-30.3%	0.0%	-6.1%
April	2.1%	-3.8%	0.9%	-0.4%
May	-0.5%	-1.6%	-0.5%	0.3%
June	-0.4%	-0.6%	-0.4%	1.6%
July	-0.6%	3.8%	-0.3%	-0.4%
August	-1.5%	4.8%	1.9%	0.9%
September	-21.4%	-6.3%	-5.7%	-2.0%

Table 10. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), longnose dace.

Average change in longnose dace habitat by month

	Juvenile		Adult	
	Wet	Average	Wet	Average
October			1.3%	-13.2%
November			4.3%	34.7%
December			6.4%	51.8%
January			8.4%	27.3%
February			7.6%	12.1%
March			0.0%	-15.2%
April			1.5%	-2.2%
May			-0.5%	-0.5%
June			-0.4%	0.6%
July			-0.5%	1.6%
August			0.2%	3.1%
September			-10.2%	-3.4%

Table 11. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), sand shiner.

Average change in sand shiner habitat by month

	Juvenile		Adult	
	Wet	Average	Wet	Average
October			-0.4%	-4.8%
November			0.7%	23.4%
December			1.7%	18.1%
January			3.4%	8.8%
February			2.7%	5.6%
March			0.0%	-2.4%
April			0.1%	0.5%
May			-0.5%	1.6%
June			-0.4%	3.5%
July			0.1%	-3.6%
August			5.4%	0.2%
September			-1.2%	-1.2%

Table 12. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), channel catfish.

Average change in channel catfish habitat by month

	Juvenile		Adult	
	Wet	Average	Wet	Average
October	-1.4%	-7.0%	3.4%	-16.2%
November	0.4%	10.5%	7.0%	41.7%
December	3.6%	-38.0%	7.1%	70.7%
January	6.7%	-26.6%	8.2%	38.0%
February	5.8%	5.8%	7.3%	12.6%
March	0.0%	-2.5%	3.8%	-24.9%
April	0.1%	1.7%	2.2%	-7.2%
May	-0.5%	1.1%	-0.5%	-2.2%
June	-0.4%	0.2%	-0.4%	-1.4%
July	-0.5%	-1.5%	-0.6%	4.2%
August	0.6%	-0.6%	-2.3%	6.5%
September	5.2%	-0.3%	-21.6%	-5.5%

Table 13. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), white sucker.

Average change in white sucker habitat by month

	Juvenile		Adult	
	Wet	Average	Wet	Average
October	0.8%	-14.4%	0.8%	-14.4%
November	3.1%	40.4%	3.1%	40.4%
December	5.5%	64.7%	5.5%	64.7%
January	8.3%	35.7%	8.3%	35.7%
February	6.6%	14.8%	6.6%	14.8%
March	2.2%	-9.9%	0.0%	-9.9%
April	1.1%	-1.3%	1.1%	-1.3%
May	-0.5%	-0.1%	-0.5%	-0.1%
June	-0.4%	1.0%	-0.4%	1.0%
July	-0.4%	0.8%	-0.4%	0.8%
August	0.8%	2.0%	0.8%	2.0%
September	-9.8%	-3.0%	-9.8%	-3.0%

Table 14. South Platte at Chatfield buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), common carp.

Average change in common carp habitat by month

	Juvenile		Adult	
	Wet	Average	Wet	Average
October			-2.0%	-13.9%
November			1.4%	34.5%
December			4.9%	47.1%
January			9.5%	21.9%
February			6.7%	13.3%
March			0.0%	-5.0%
April			-0.7%	2.2%
May			-0.5%	2.5%
June			-0.4%	3.8%
July			0.0%	-9.1%
August			7.8%	-0.5%
September			-0.1%	-2.5%

Table 15. South Platte at Burlington Ditch current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), longnose dace.

Average change in longnose dace habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			3.7%	25.6%
November			8.8%	6.7%
December			10.6%	19.3%
January			11.6%	15.7%
February			10.0%	11.7%
March			0.0%	4.8%
April			-2.0%	6.6%
May			-9.6%	1.4%
June			-8.5%	-3.5%
July			-1.3%	-2.9%
August			2.7%	-1.4%
September			-11.5%	-6.7%

Table 16. South Platte at Burlington Ditch current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), sand shiner.

Average change in sand shiner habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			-1.7%	13.4%
November			-0.5%	0.2%
December			-0.7%	4.7%
January			-0.7%	3.7%
February			0.1%	1.1%
March			0.0%	0.4%
April			-5.4%	3.3%
May			-9.6%	0.2%
June			-8.5%	0.3%
July			8.4%	1.0%
August			1.0%	2.0%
September			-0.4%	0.0%

Table 17. South Platte at Burlington Ditch current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), channel catfish.

Average change in channel catfish habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October	1.0%	17.5%	6.1%	22.6%
November	0.1%	1.8%	3.7%	8.8%
December	0.0%	11.4%	11.9%	19.0%
January	-0.4%	9.1%	12.2%	16.1%
February	-0.7%	5.5%	8.0%	14.2%
March	1.7%	1.9%	0.0%	6.3%
April	-2.3%	4.4%	-5.9%	6.8%
May	-9.6%	0.6%	-9.6%	1.5%
June	-8.5%	-0.2%	-8.5%	-2.5%
July	-1.4%	-0.5%	-0.2%	-0.1%
August	2.8%	-0.9%	2.8%	0.9%
September	-0.1%	-0.6%	-14.9%	-6.6%

Table 18. South Platte at Burlington Ditch current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), white sucker.

Average change in white sucker habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October	4.8%	55.0%	4.8%	55.0%
November	2.2%	9.4%	2.2%	9.4%
December	9.8%	40.2%	9.8%	40.2%
January	9.5%	29.8%	9.5%	29.8%
February	5.2%	21.1%	5.2%	21.1%
March	-1.3%	7.8%	0.0%	7.8%
April	-74.4%	9.9%	-74.4%	9.9%
May	-9.6%	2.4%	-9.6%	2.4%
June	-8.5%	-1.8%	-8.5%	-1.8%
July	6.2%	0.6%	6.2%	0.6%
August	1.6%	1.2%	1.6%	1.2%
September	-13.0%	-5.8%	-13.0%	-5.8%

Table 19. South Platte at Burlington Ditch current conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), common carp.

Average change in common carp habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			4.0%	15.8%
November			5.3%	3.3%
December			10.9%	7.3%
January			11.6%	6.0%
February			11.2%	3.4%
March			0.0%	1.5%
April			-4.2%	4.0%
May			-9.6%	0.6%
June			-8.5%	-2.5%
July			2.4%	-0.3%
August			2.4%	1.8%
September			-9.7%	-4.6%

Table 20. South Platte at Burlington Ditch buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), longnose dace.

Average change in longnose dace habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			3.1%	22.1%
November			4.7%	11.4%
December			4.2%	34.1%
January			4.3%	34.2%
February			3.3%	27.3%
March			0.0%	20.1%
April			2.0%	43.4%
May			-0.1%	3.4%
June			-0.2%	-9.9%
July			-0.9%	-4.7%
August			-2.2%	-2.7%
September			-15.7%	-6.3%

Table 21. South Platte at Burlington Ditch buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), sand shiner.

Average change in sand shiner habitat by month	Juvenile		Adult	
	Wet	Average	Wet	Average
October			-0.4%	19.1%
November			-0.2%	4.3%
December			-0.2%	20.0%
January			-0.2%	20.8%
February			-0.1%	13.1%
March			0.0%	8.0%
April			0.5%	41.8%
May			-0.1%	1.1%
June			-0.2%	-1.1%
July			-0.1%	0.5%
August			1.5%	0.3%
September			1.1%	-0.3%

Table 22. South Platte at Burlington Ditch buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), channel catfish.

Average change in channel catfish habitat by month	Juvenile		Adult	
	Wet	Average	Wet	Average
October	0.7%	19.6%	3.6%	20.6%
November	0.0%	6.9%	4.4%	12.8%
December	0.1%	23.8%	4.5%	30.2%
January	-0.1%	24.2%	4.7%	30.4%
February	-0.1%	18.0%	2.9%	23.7%
March	0.2%	12.6%	0.0%	17.4%
April	1.1%	42.5%	1.2%	43.4%
May	-0.1%	1.8%	-0.1%	3.2%
June	-0.2%	-4.1%	-0.2%	-10.0%
July	-1.0%	-0.2%	-1.0%	-2.8%
August	-1.8%	-0.1%	-0.4%	-0.3%
September	-1.5%	-1.9%	-17.3%	-6.7%

Table 23. South Platte at Burlington Ditch buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), white sucker.

Average change in white sucker habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October	3.1%	52.2%	3.1%	52.2%
November	3.4%	21.7%	3.4%	21.7%
December	3.7%	78.3%	3.7%	78.3%
January	3.7%	78.5%	3.7%	78.5%
February	2.1%	69.6%	2.1%	69.6%
March	-0.2%	52.7%	0.0%	52.7%
April	2.5%	10.1%	2.5%	10.1%
May	-0.1%	9.5%	-0.1%	9.5%
June	-0.2%	-36.3%	-0.2%	-36.3%
July	-0.3%	-2.1%	-0.3%	-2.1%
August	0.6%	0.0%	0.6%	0.0%
September	-15.8%	-10.1%	-15.8%	-10.1%

Table 24. South Platte at Burlington Ditch buildout conditions, percent change in habitat from reallocation to reallocation with environmental releases (ER), common carp.

Average change in common carp habitat by month				
	Juvenile		Adult	
	Wet	Average	Wet	Average
October			1.8%	19.7%
November			4.1%	5.7%
December			4.5%	23.7%
January			4.5%	24.5%
February			3.5%	15.7%
March			0.0%	9.7%
April			0.8%	42.2%
May			-0.1%	1.7%
June			-0.2%	-3.7%
July			-0.7%	-3.0%
August			0.5%	-0.9%
September			-10.4%	-3.3%

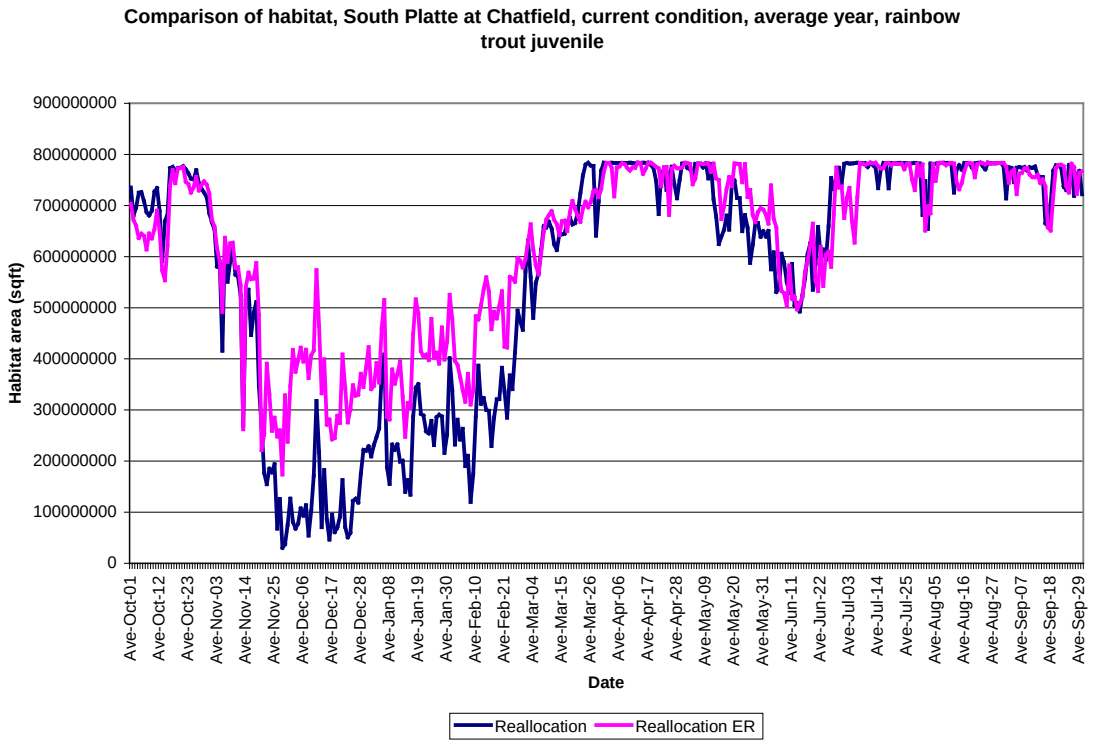


Figure 1. Comparison of habitat area, South Platte at Chatfield, current condition, average year, juvenile rainbow trout.

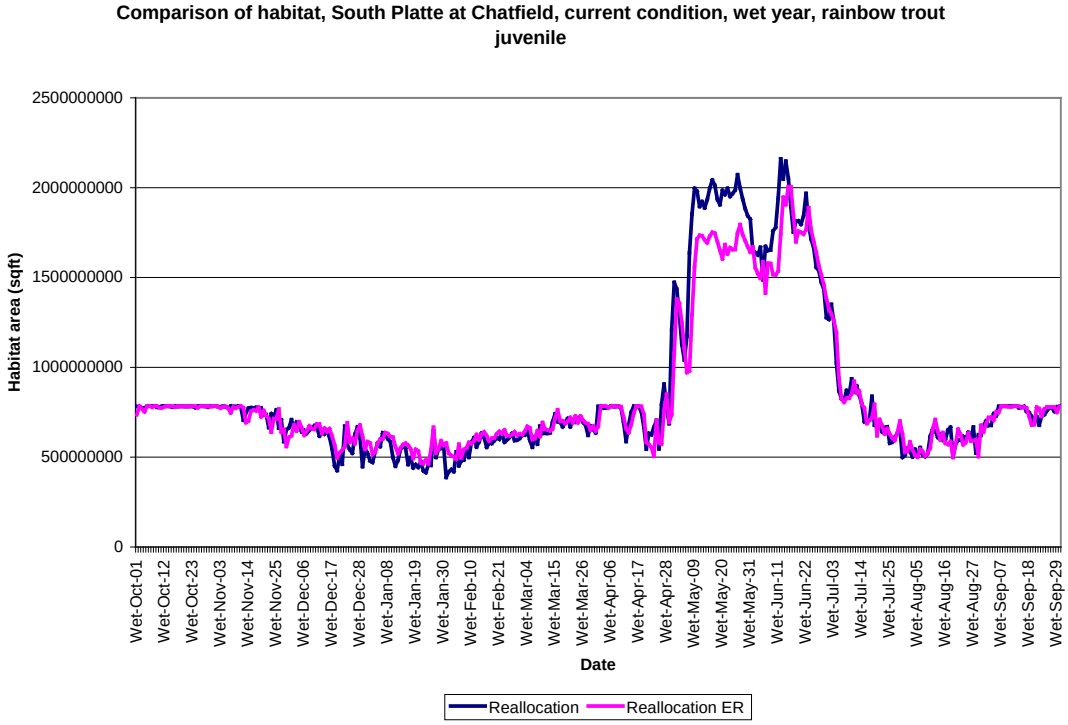


Figure 2. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, juvenile rainbow trout.

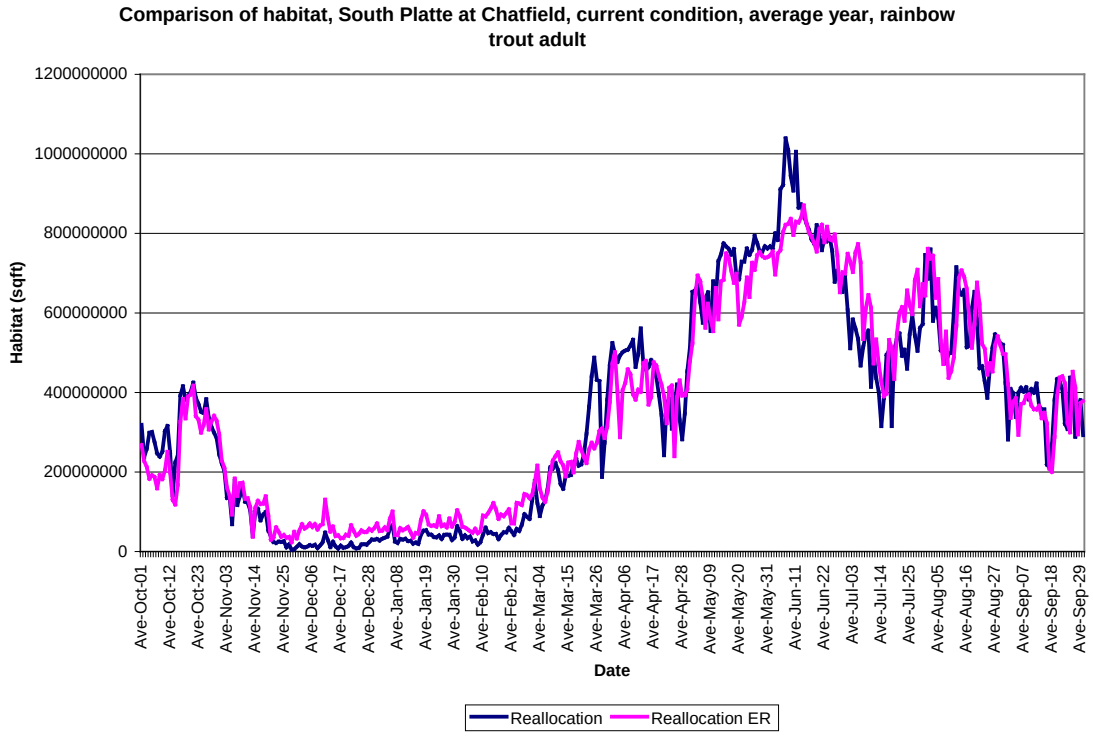


Figure 3. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult rainbow trout.

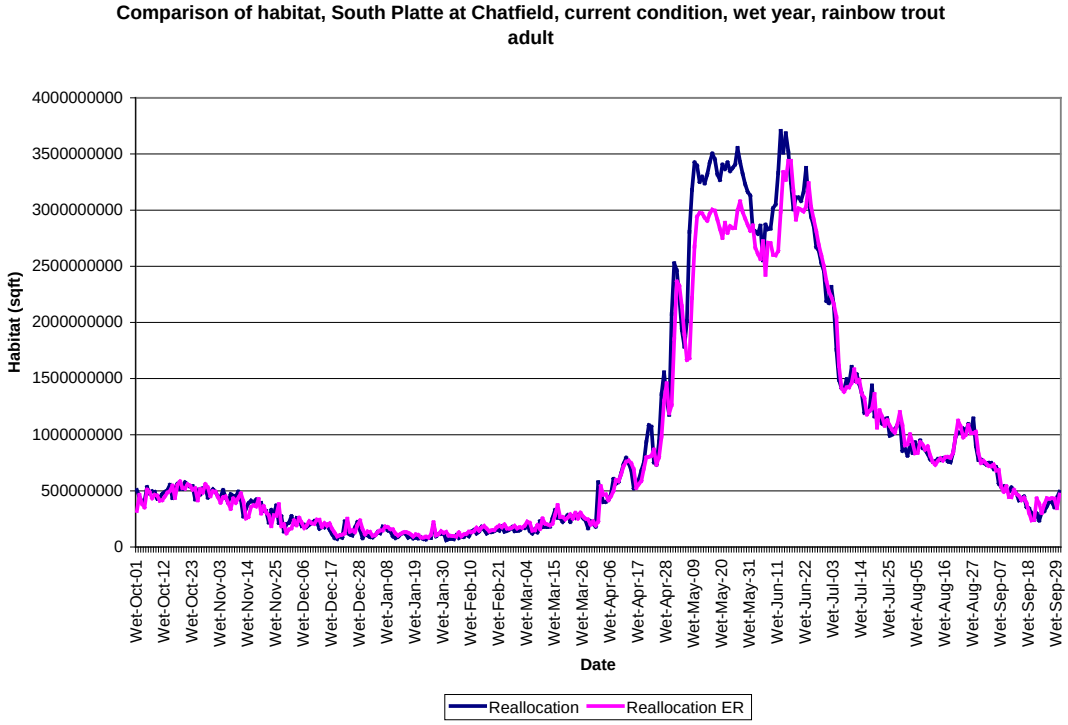


Figure 4. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult rainbow trout.

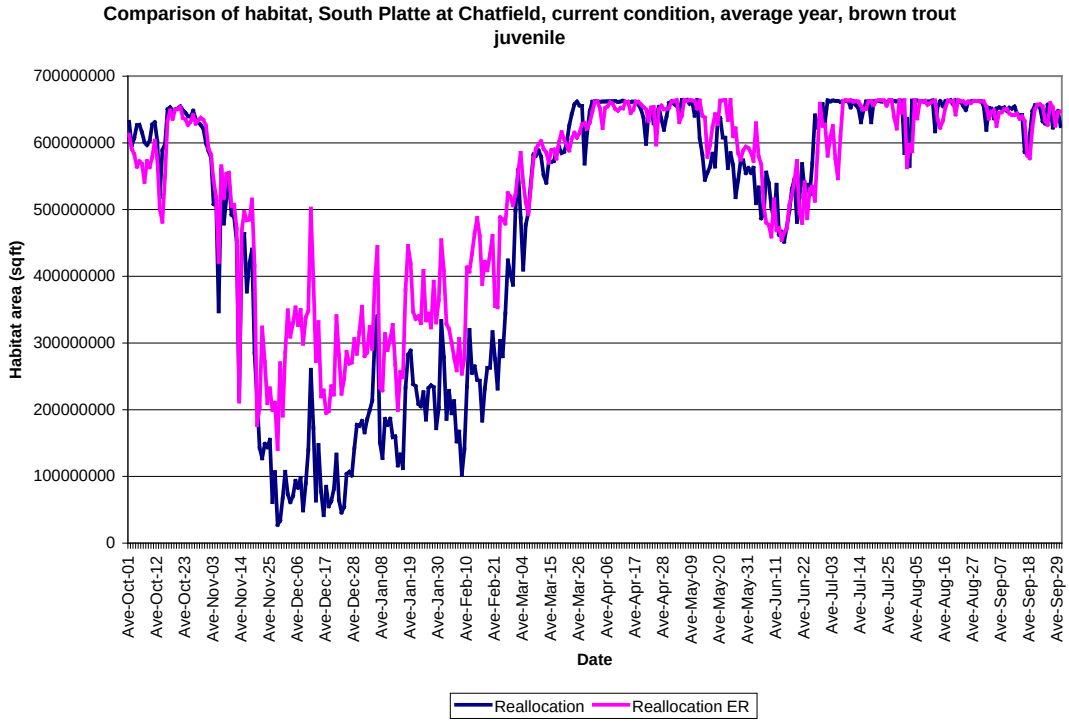


Figure 5. Comparison of habitat area, South Platte at Chatfield, current condition, average year, juvenile brown trout.

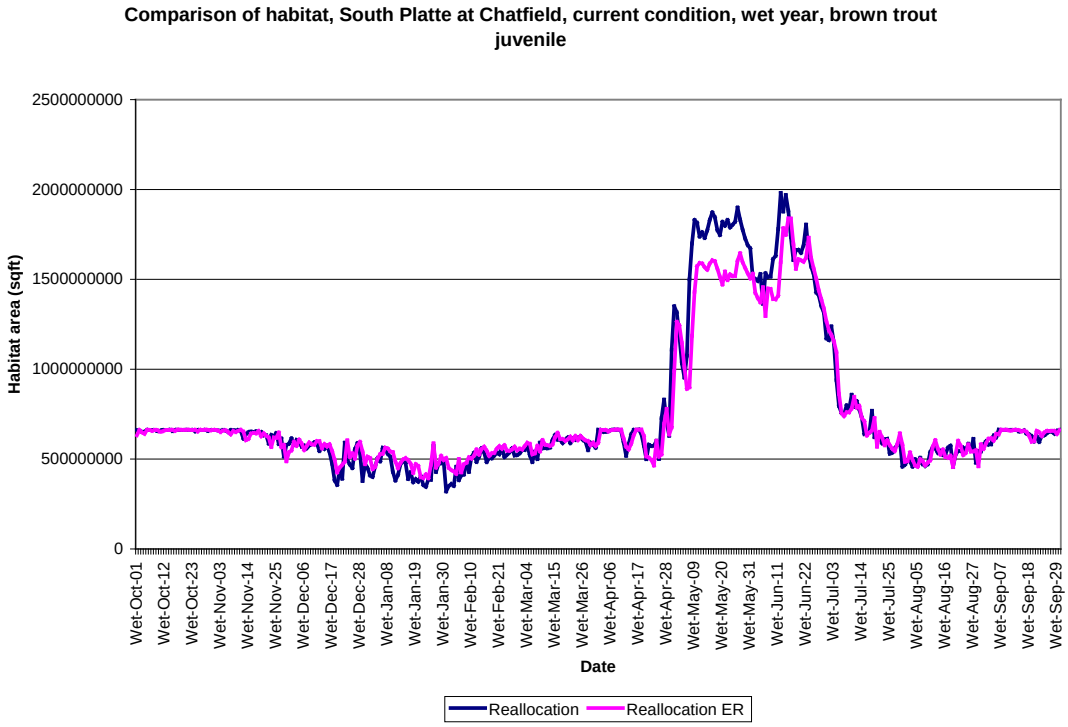


Figure 6. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, juvenile brown trout.

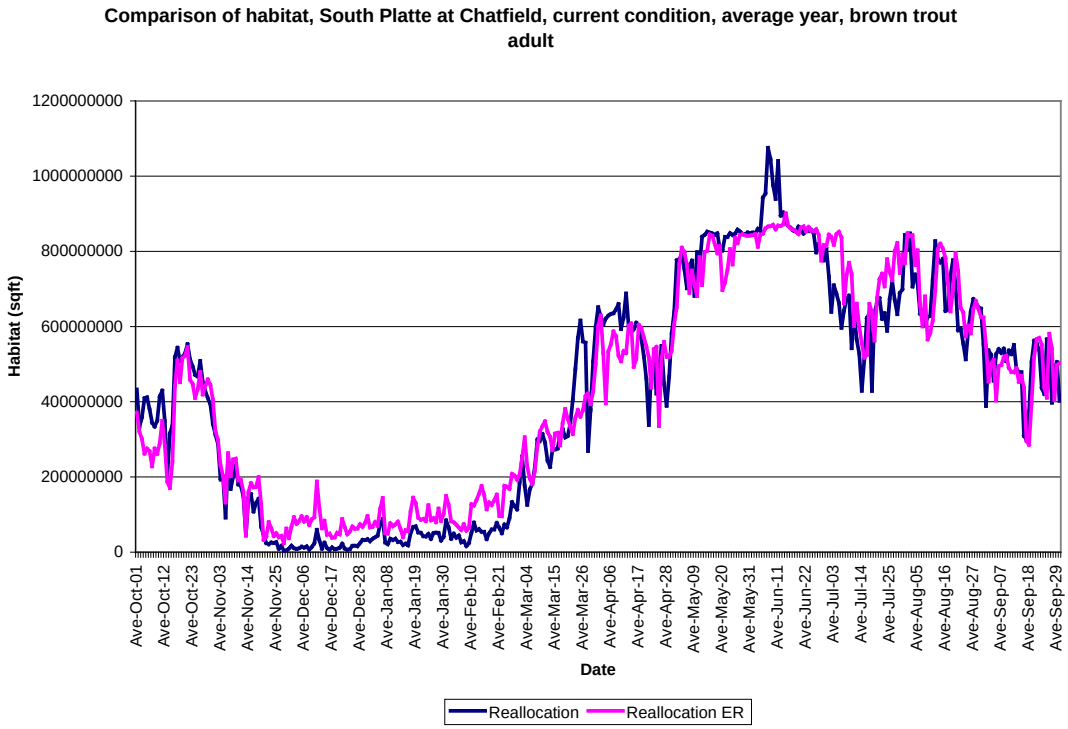


Figure 7. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult brown trout.

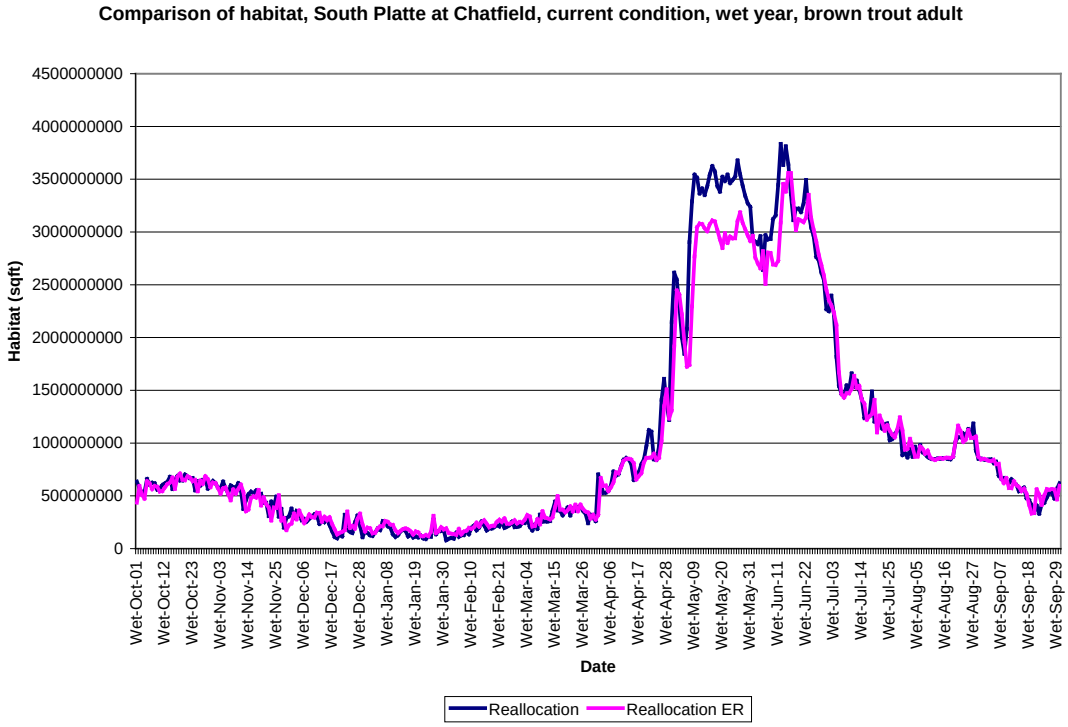


Figure 8. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult brown trout.

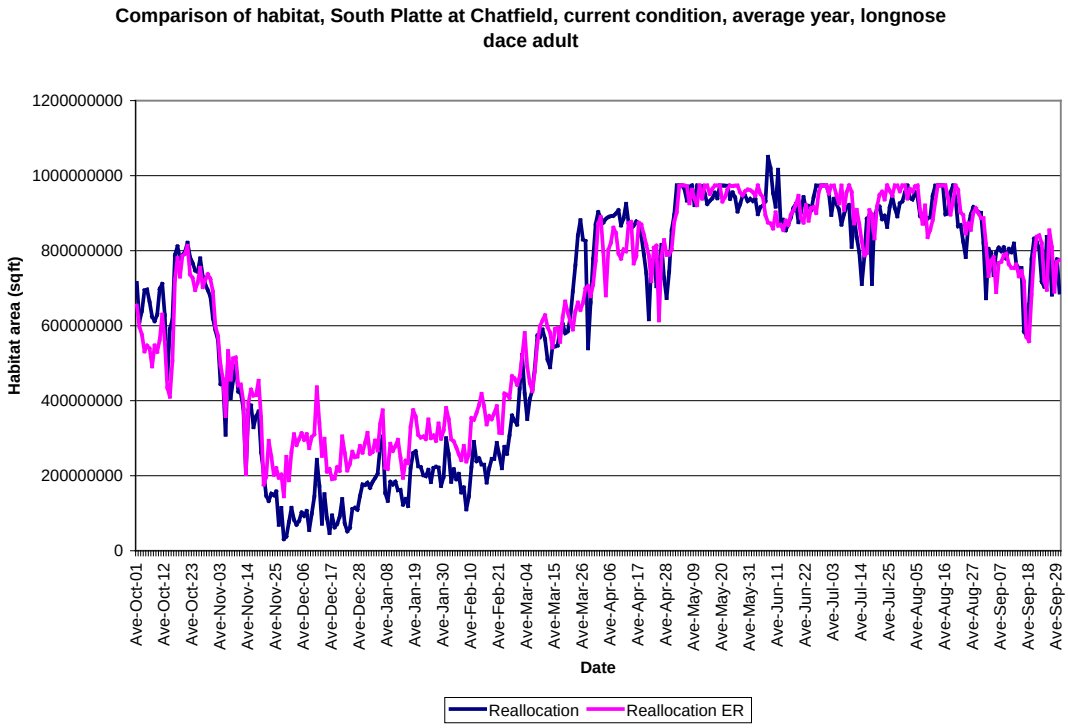


Figure 9. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult longnose dace.

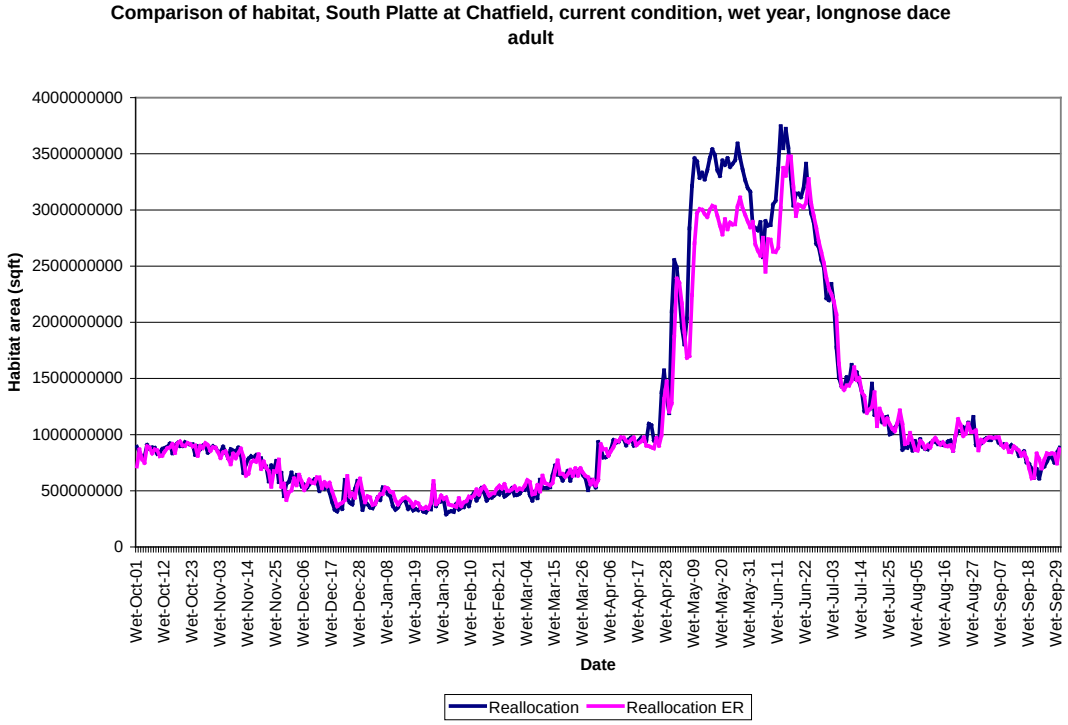


Figure 10. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult longnose dace.

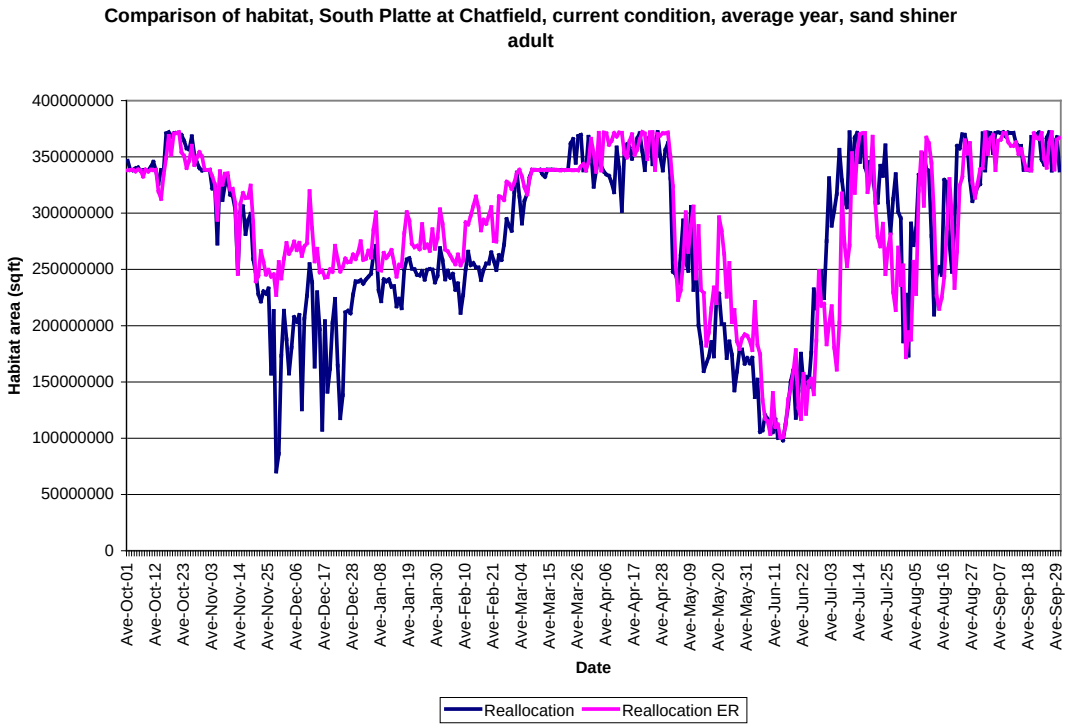


Figure 11. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult sand shiner.

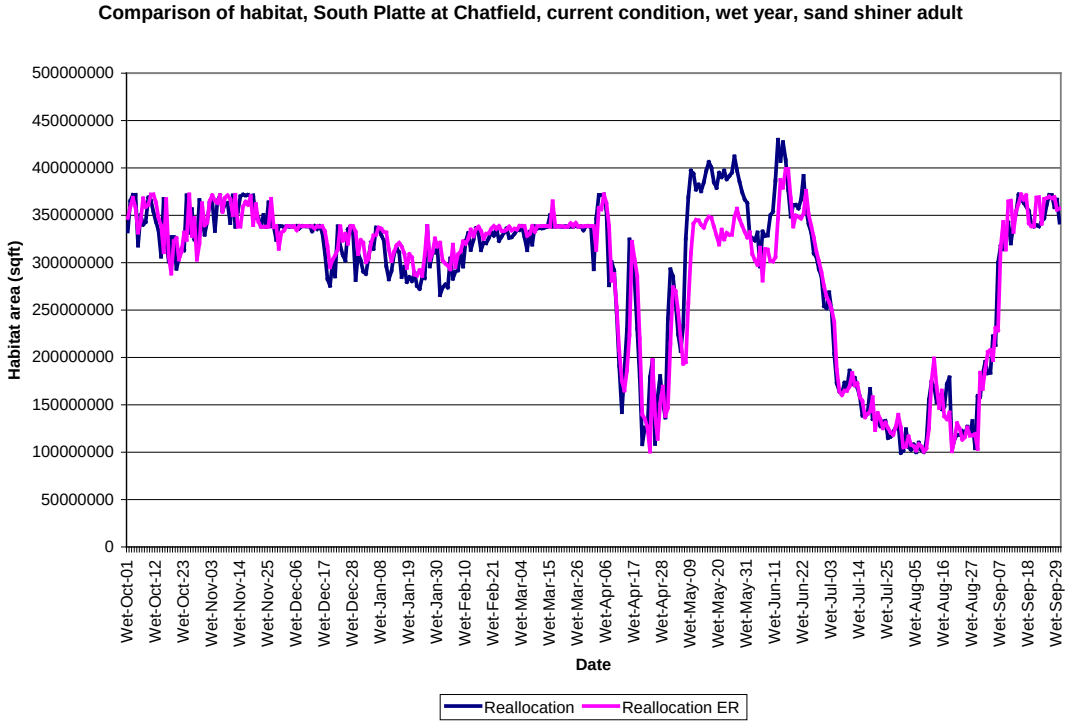


Figure 12. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult sand shiner.

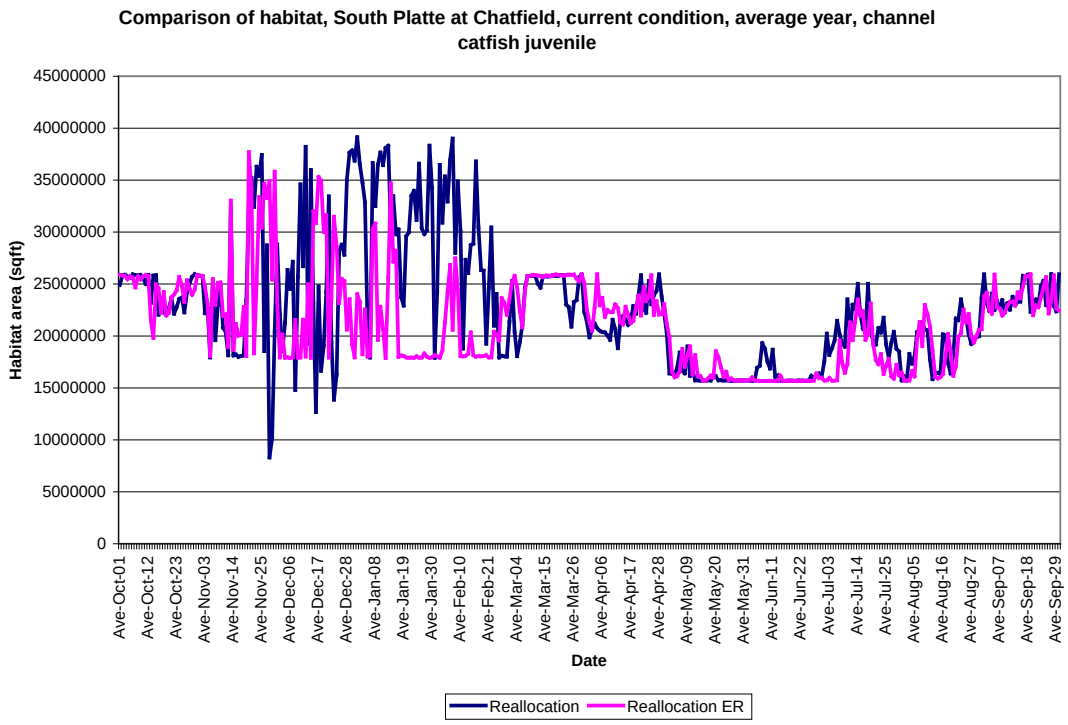


Figure 13. Comparison of habitat area, South Platte at Chatfield, current condition, average year, juvenile channel catfish.

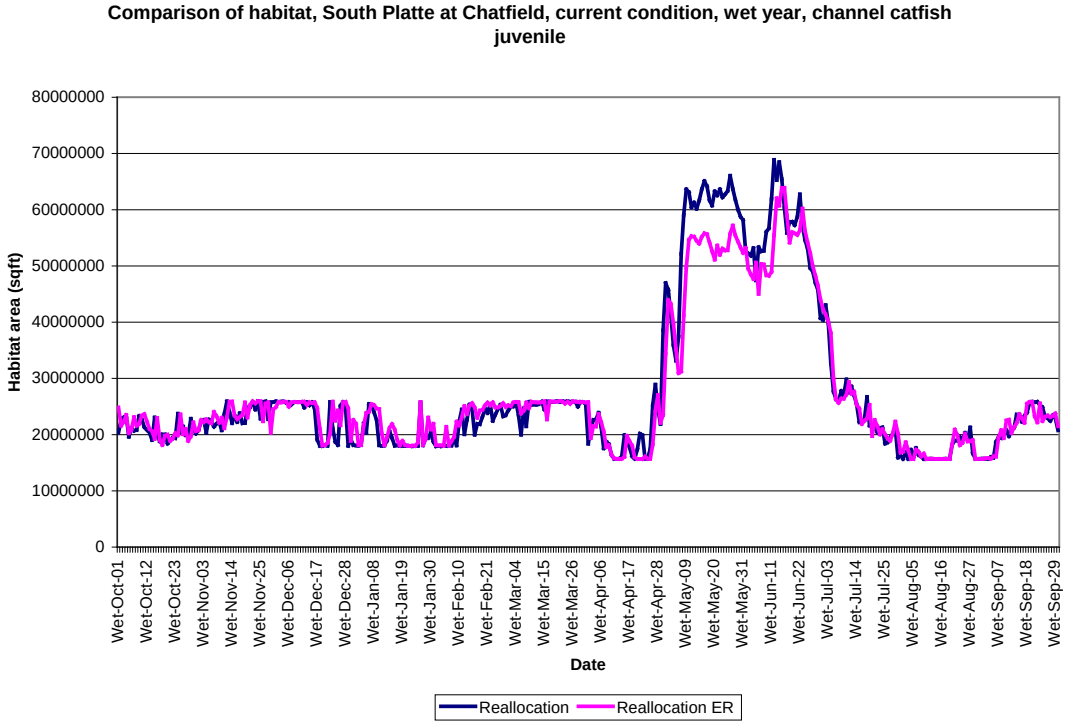


Figure 14. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, juvenile channel catfish.

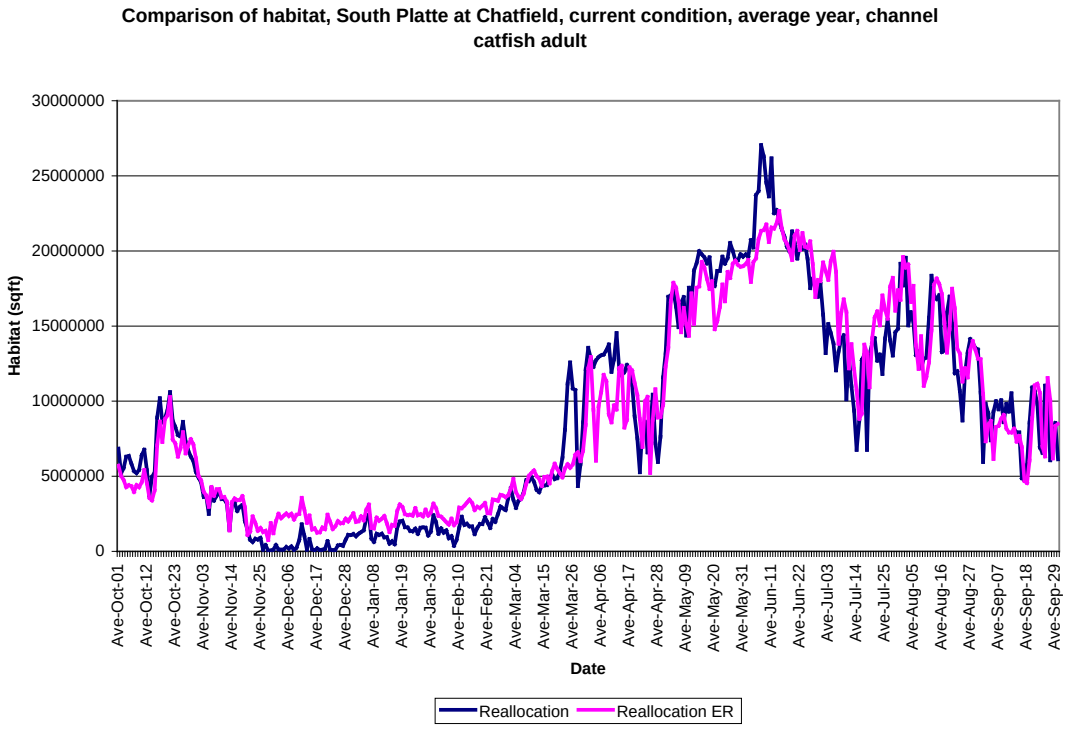


Figure 15. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult channel catfish.

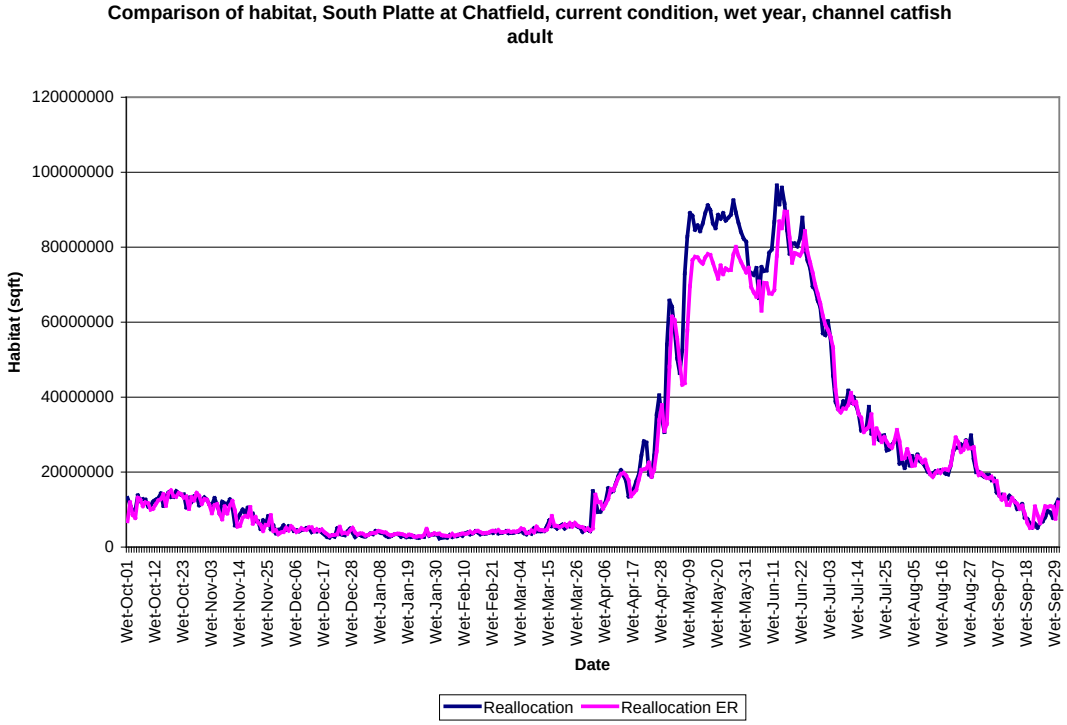


Figure 16. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult channel catfish.

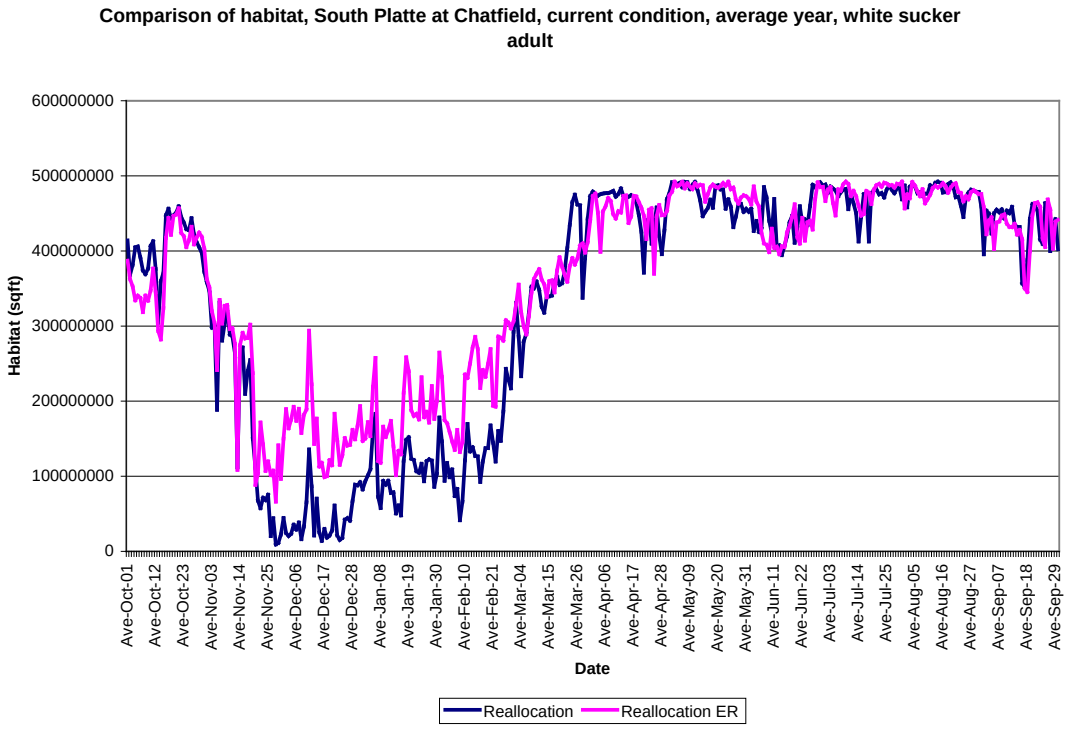


Figure 17. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult white sucker.

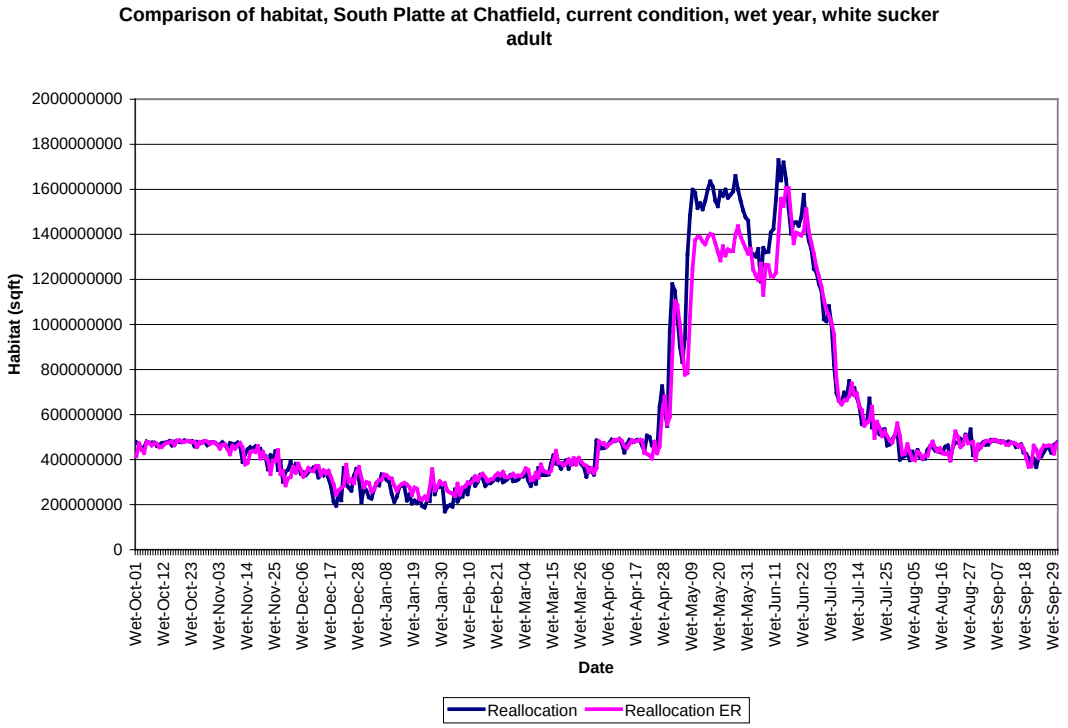


Figure 18. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult white sucker.

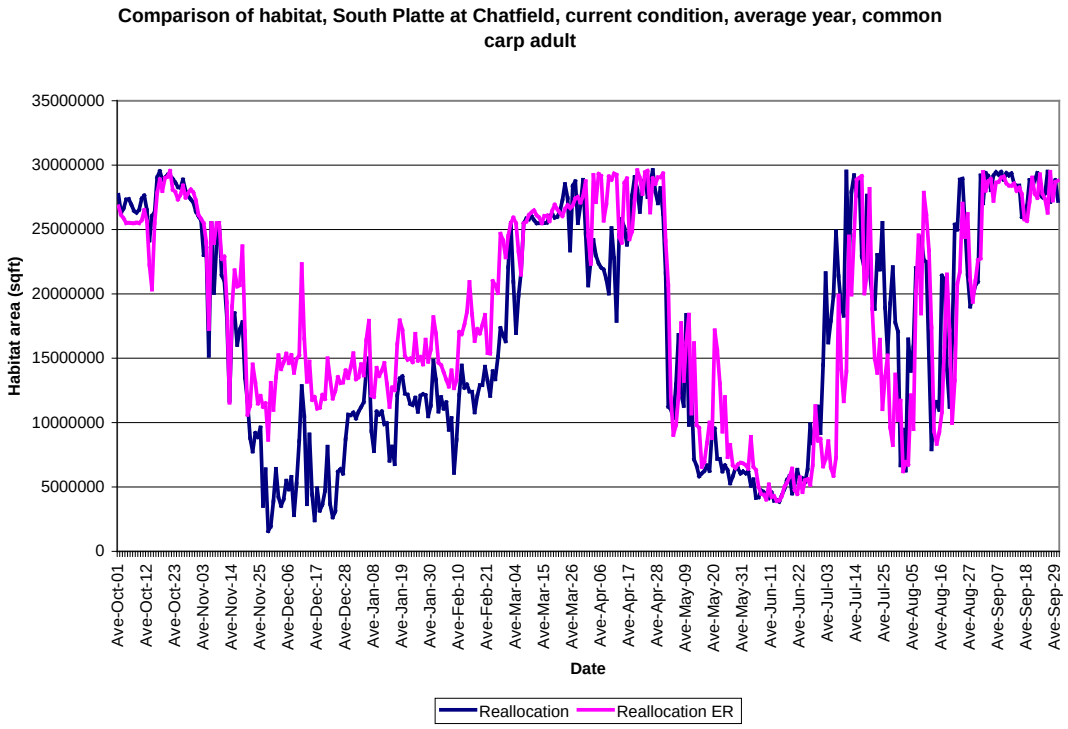


Figure 19. Comparison of habitat area, South Platte at Chatfield, current condition, average year, adult common carp.

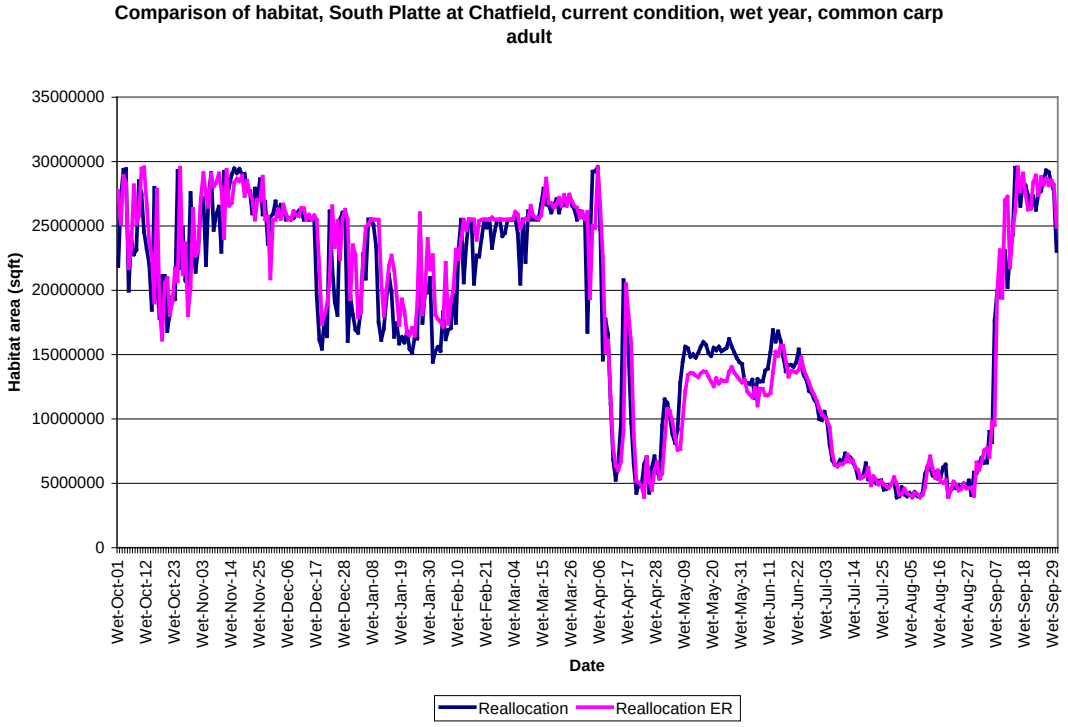


Figure 20. Comparison of habitat area, South Platte at Chatfield, current condition, wet year, adult common carp.

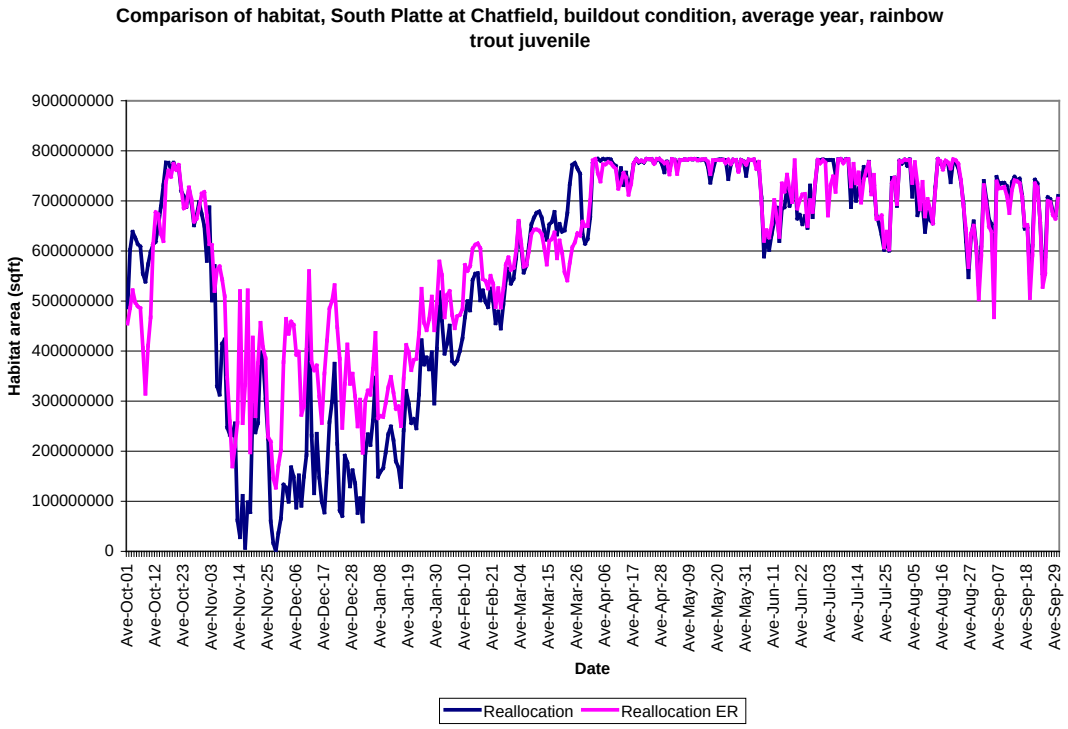


Figure 21. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, juvenile rainbow trout.

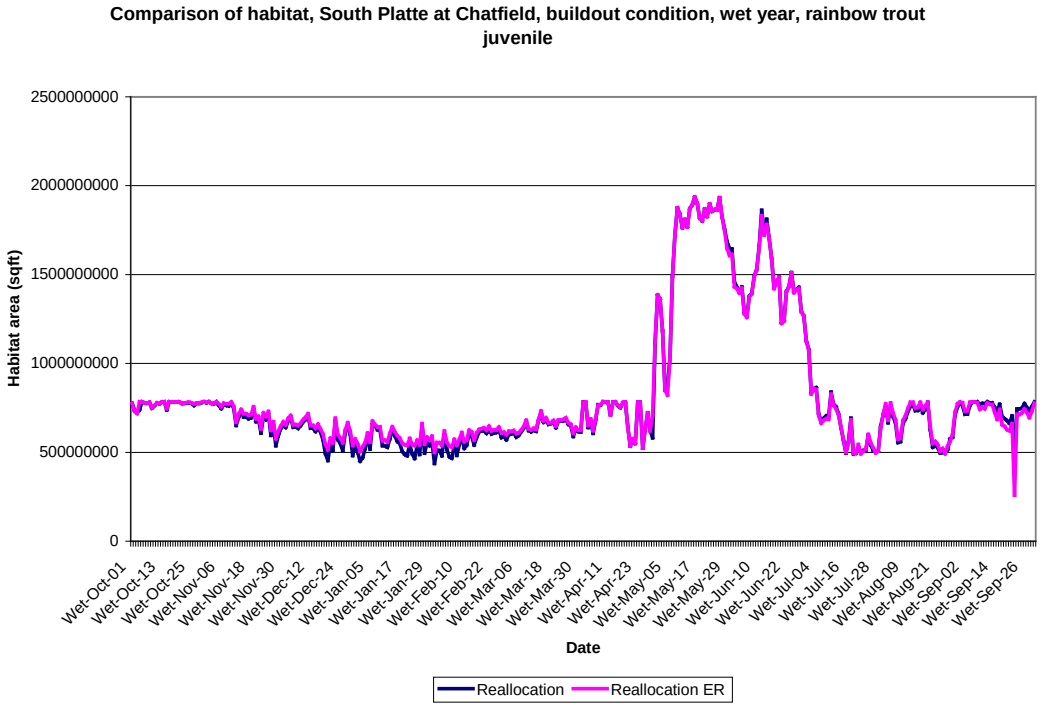


Figure 22. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, juvenile rainbow trout.

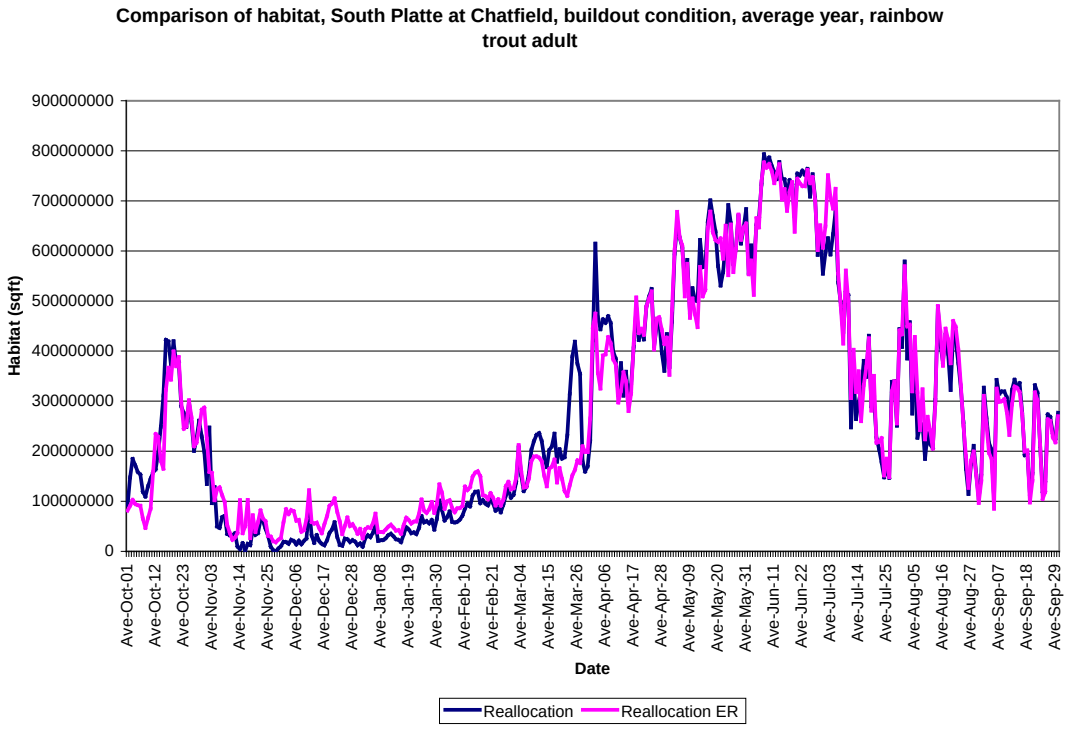


Figure 23. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult rainbow trout.

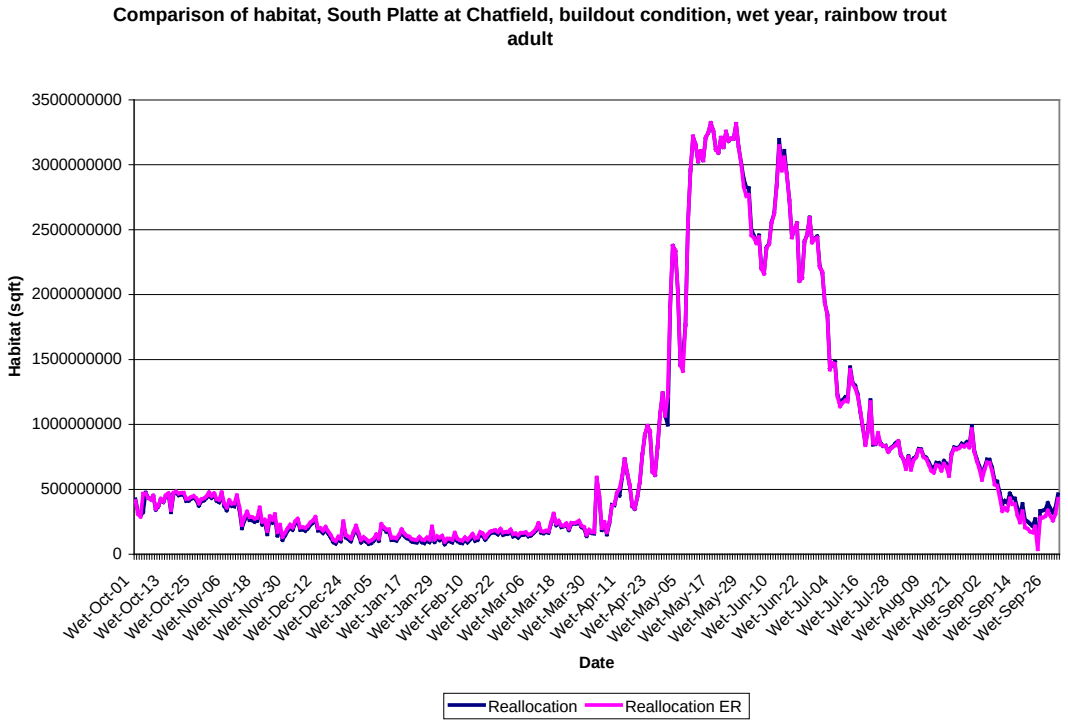


Figure 24. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult rainbow trout.

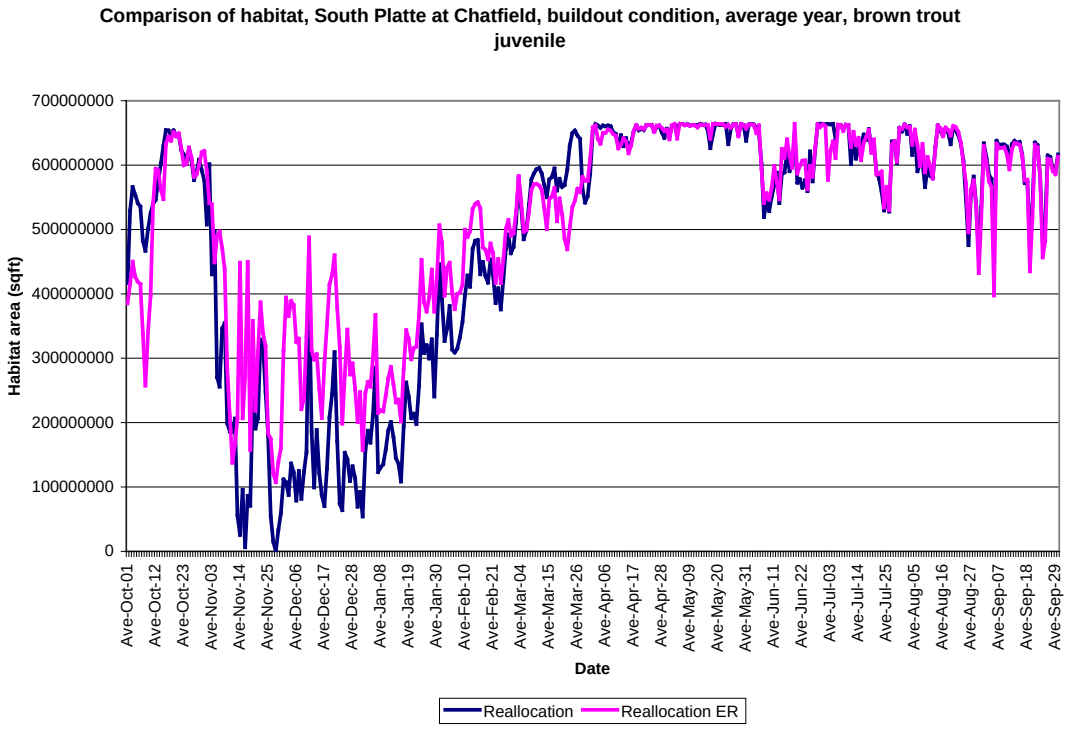


Figure 25. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, juvenile brown trout.

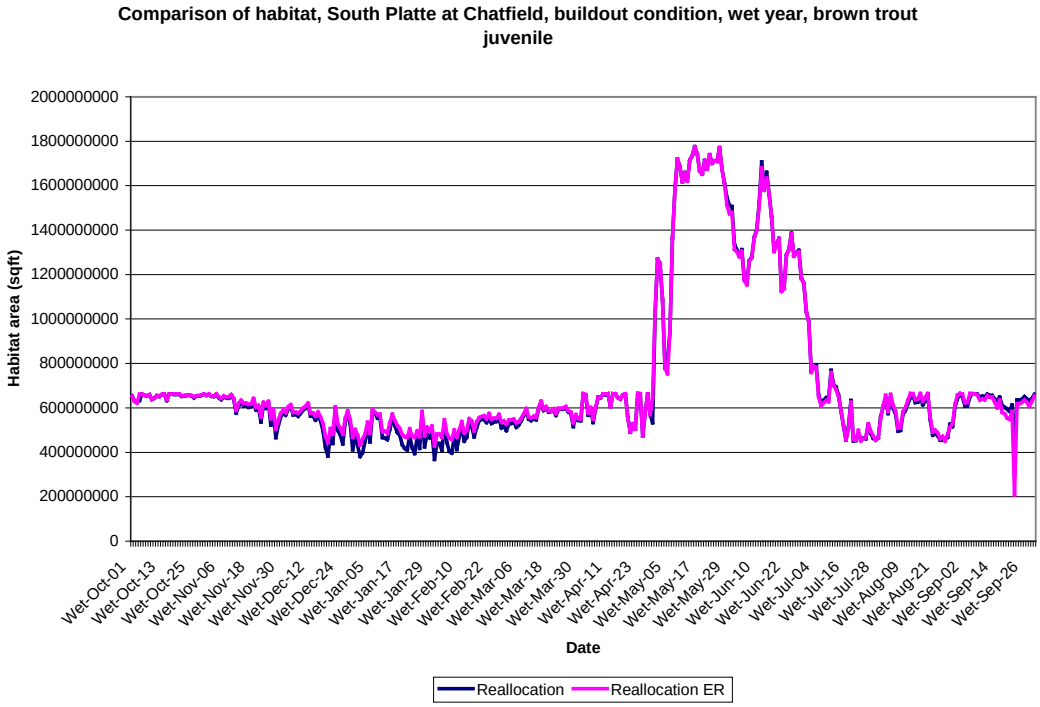


Figure 26. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, juvenile brown trout.

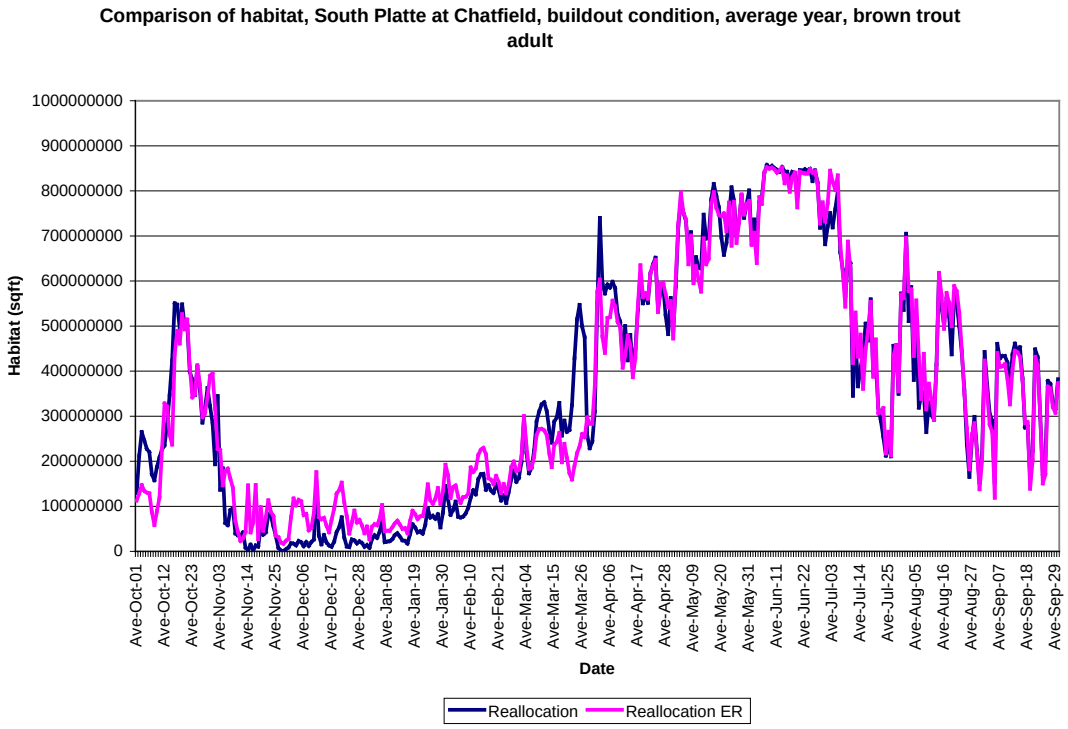


Figure 27. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult brown trout.

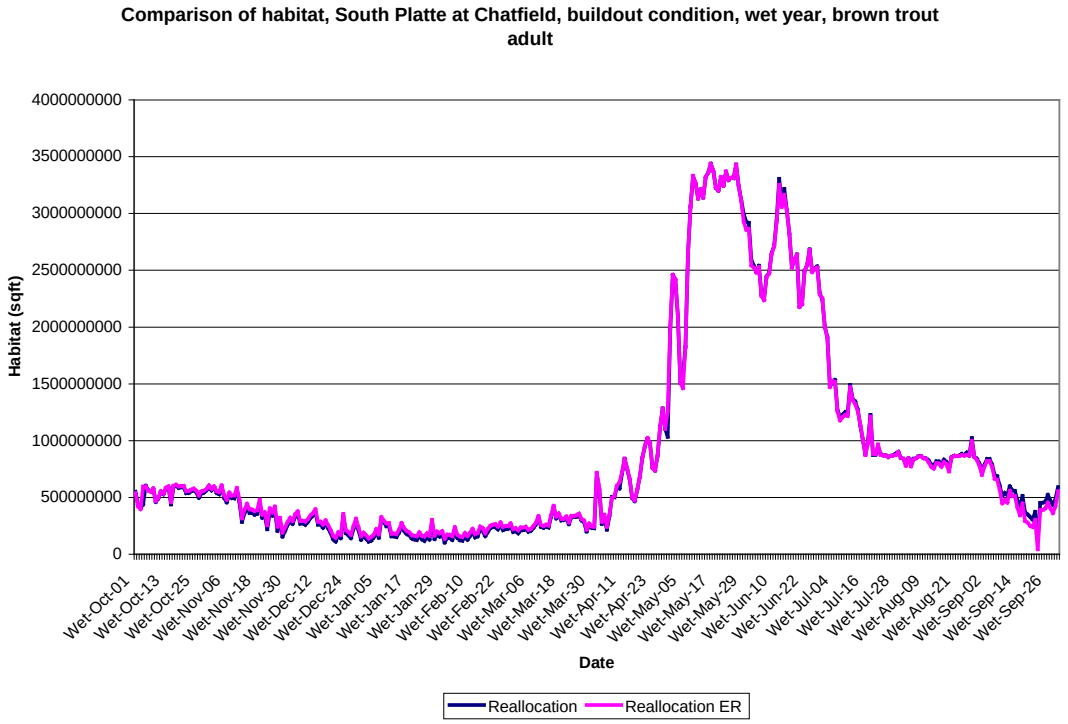


Figure 28. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult brown trout.

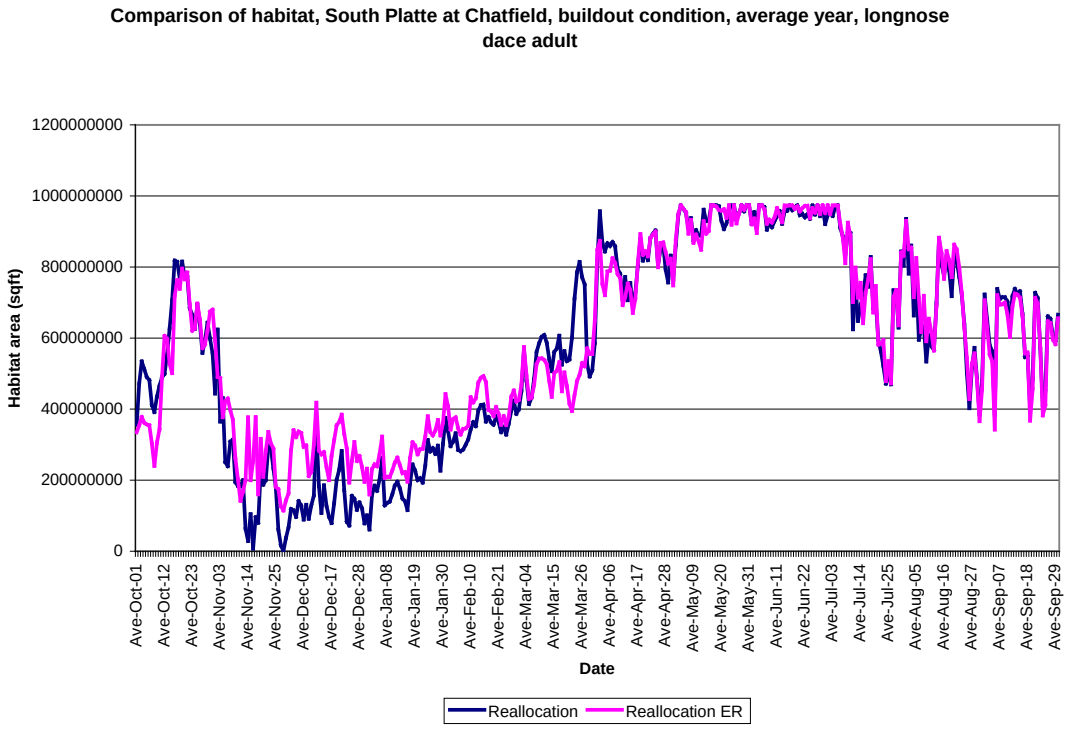


Figure 29. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult longnose dace.

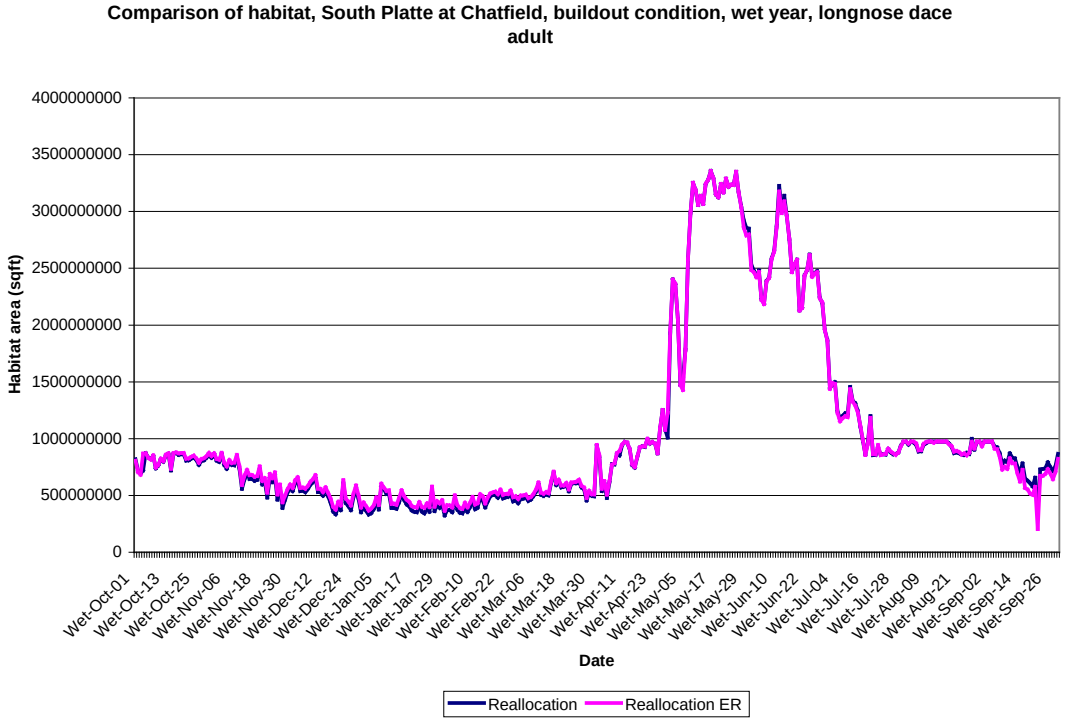


Figure 30. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult longnose dace.

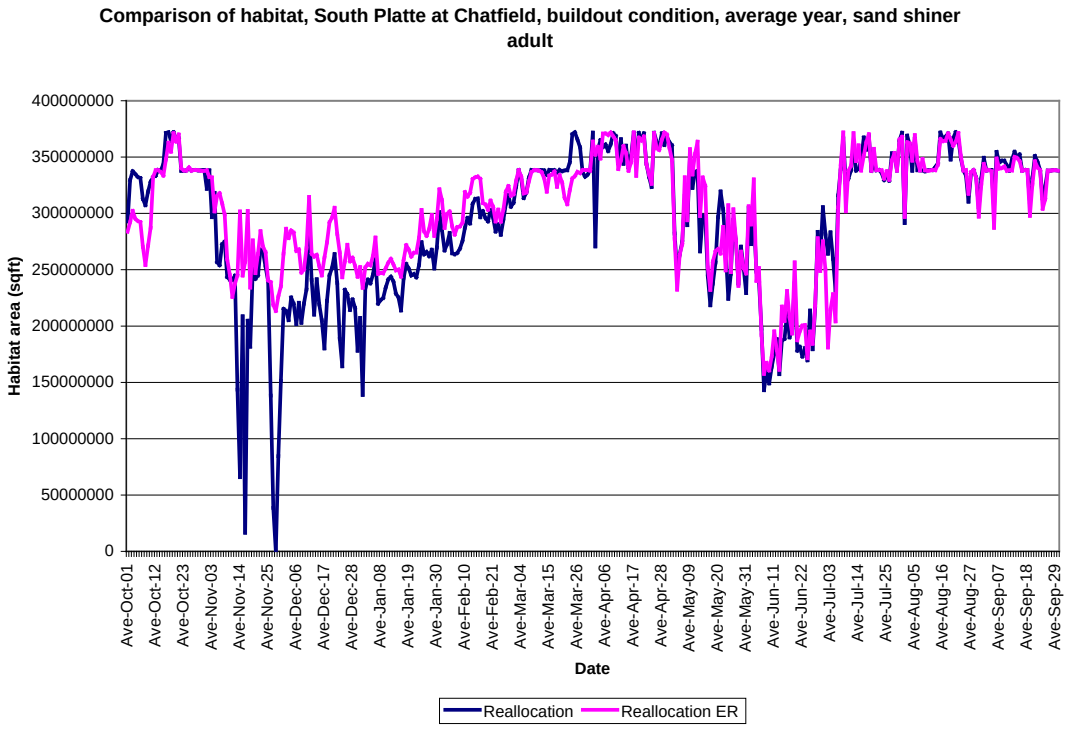


Figure 31. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult sand shiner.

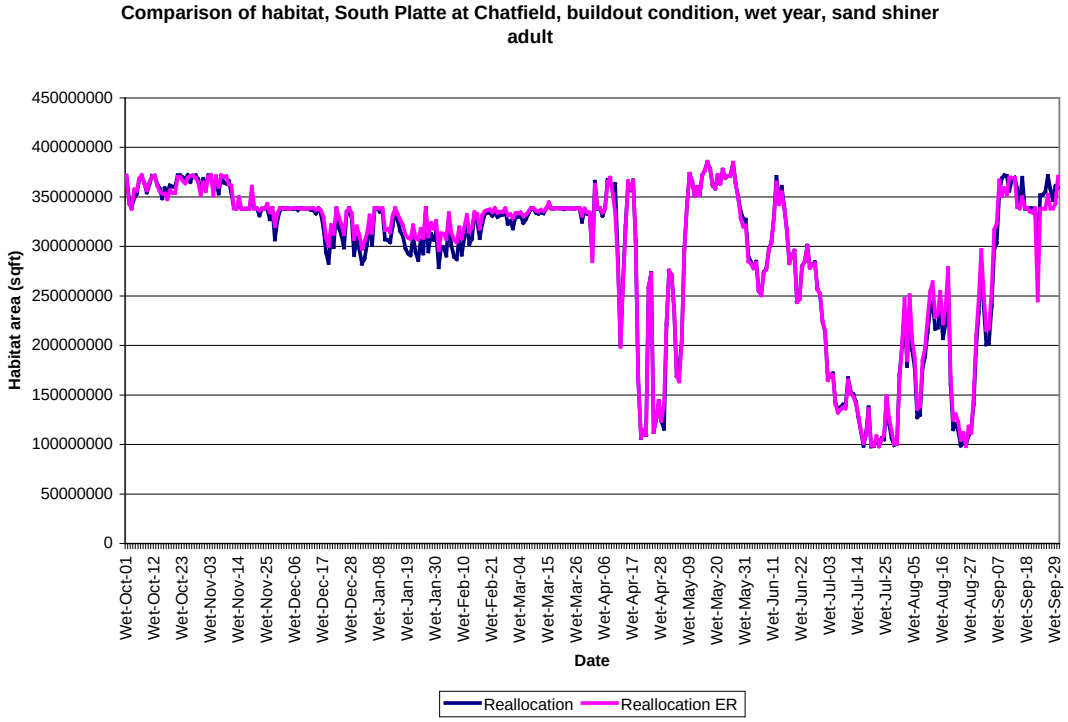


Figure 32. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult sand shiner.

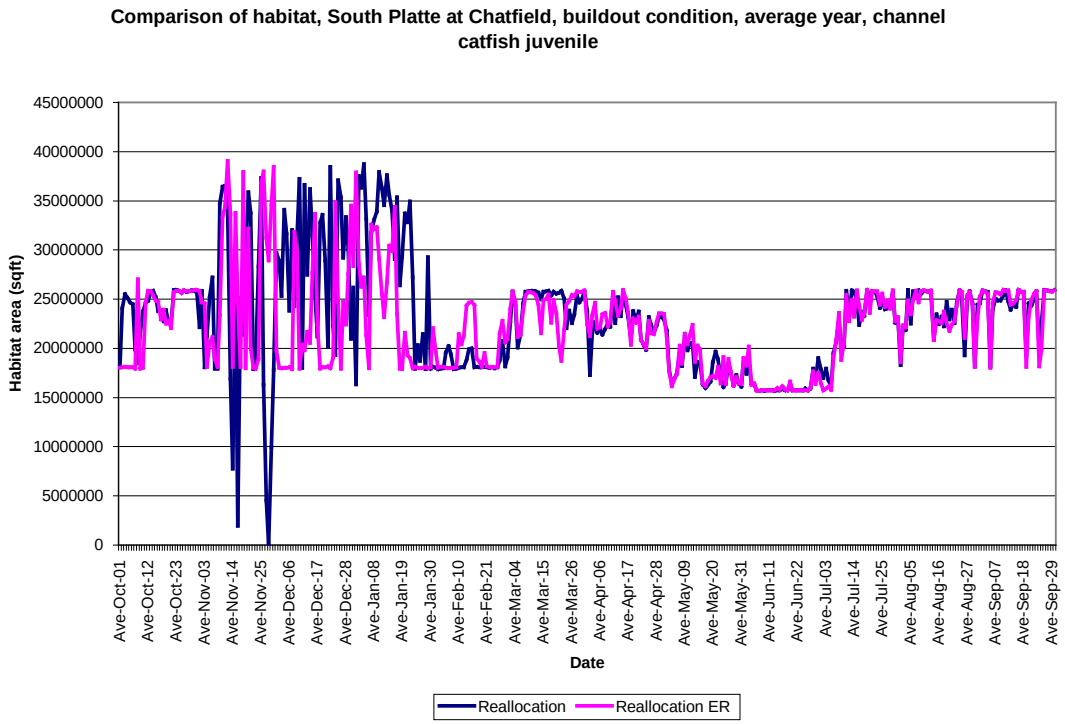


Figure 33. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, juvenile channel catfish.

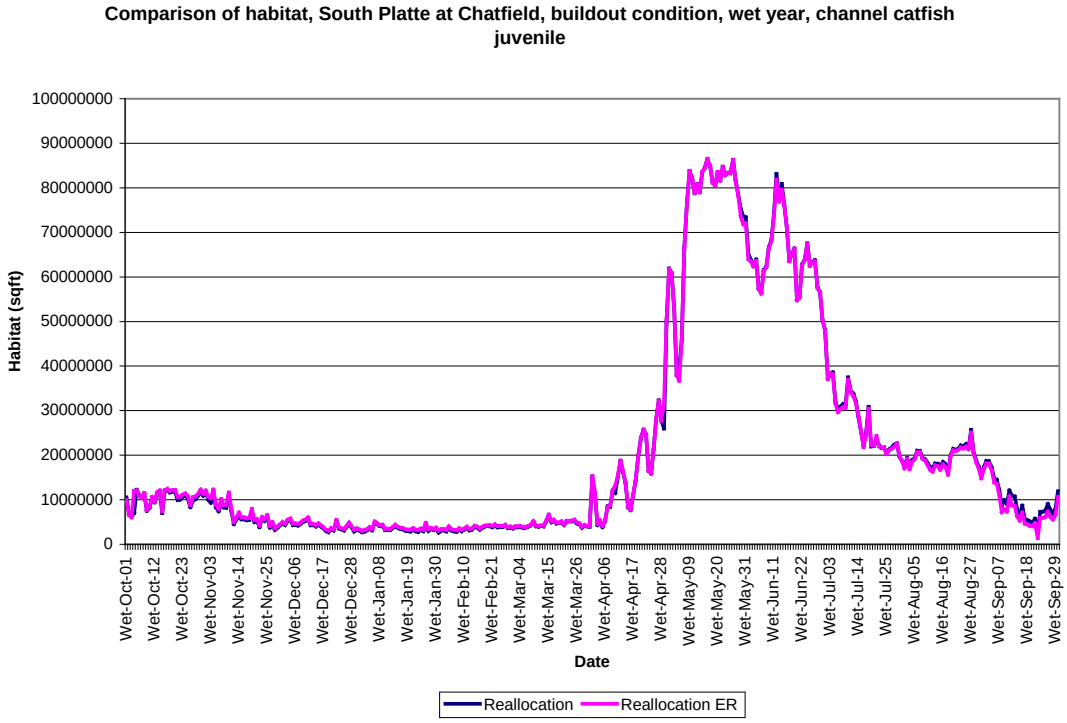


Figure 34. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, juvenile channel catfish.

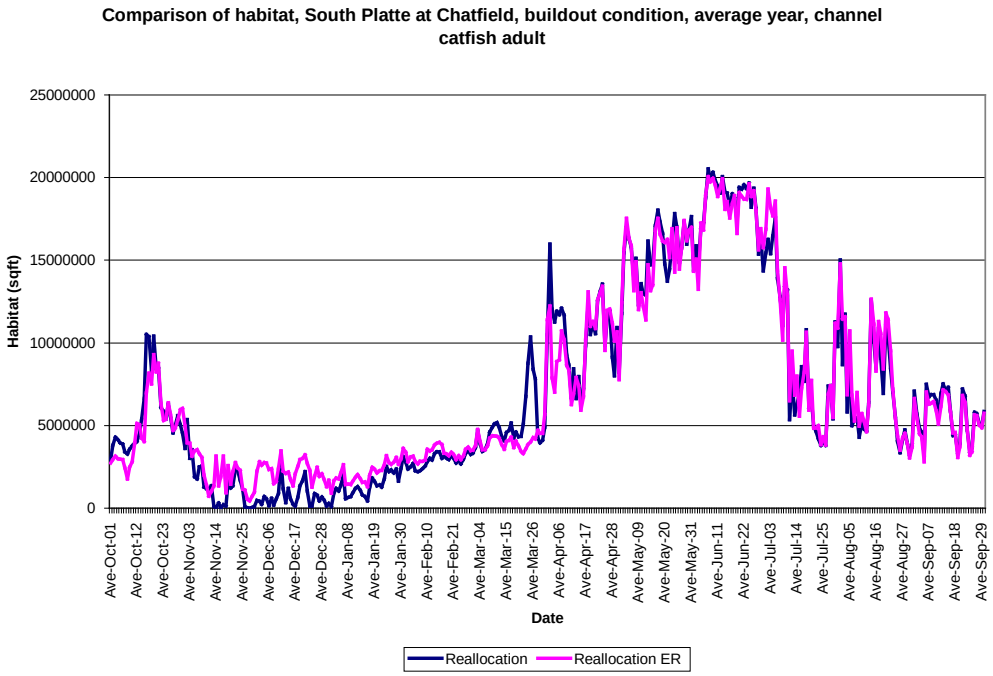


Figure 35. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult channel catfish.

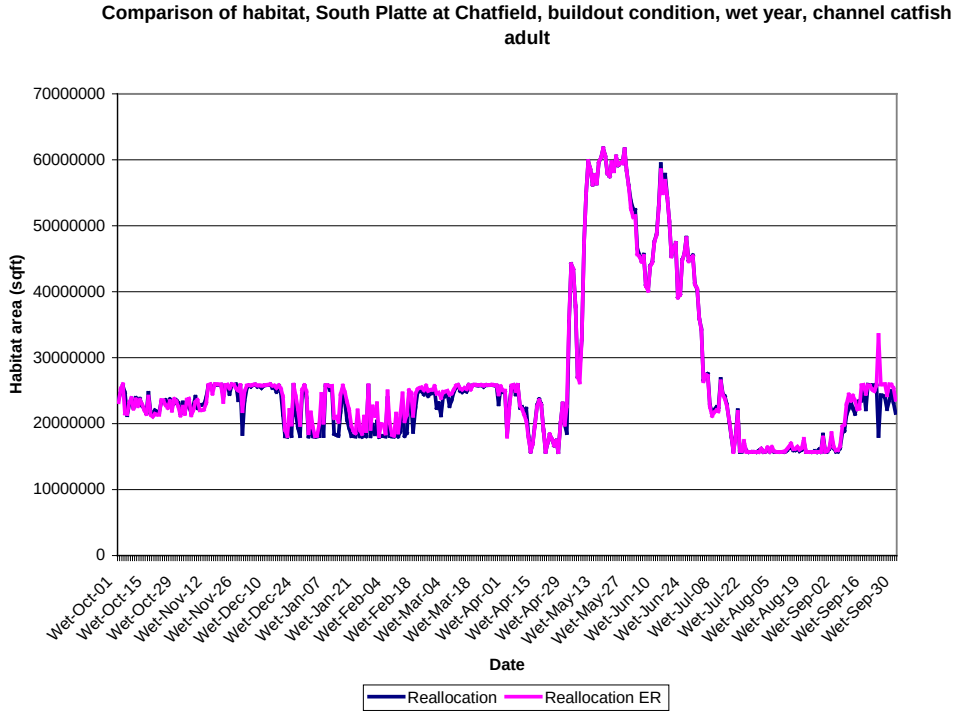


Figure 36. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult channel catfish.

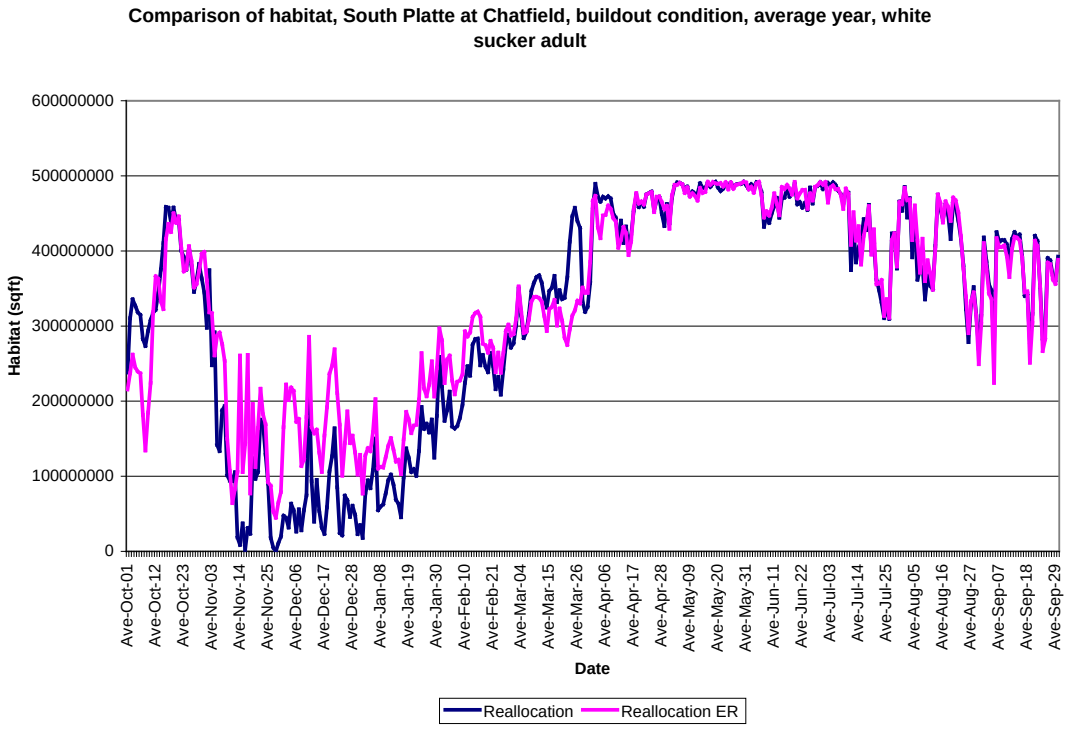


Figure 37. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult white sucker.

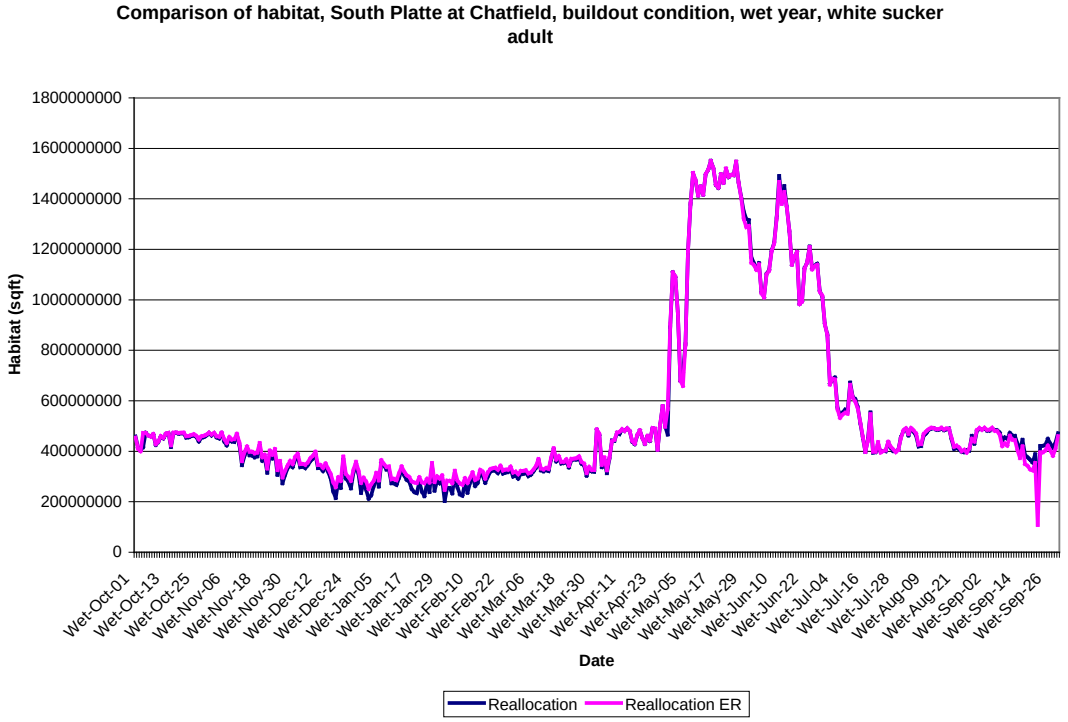


Figure 38. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult white sucker.

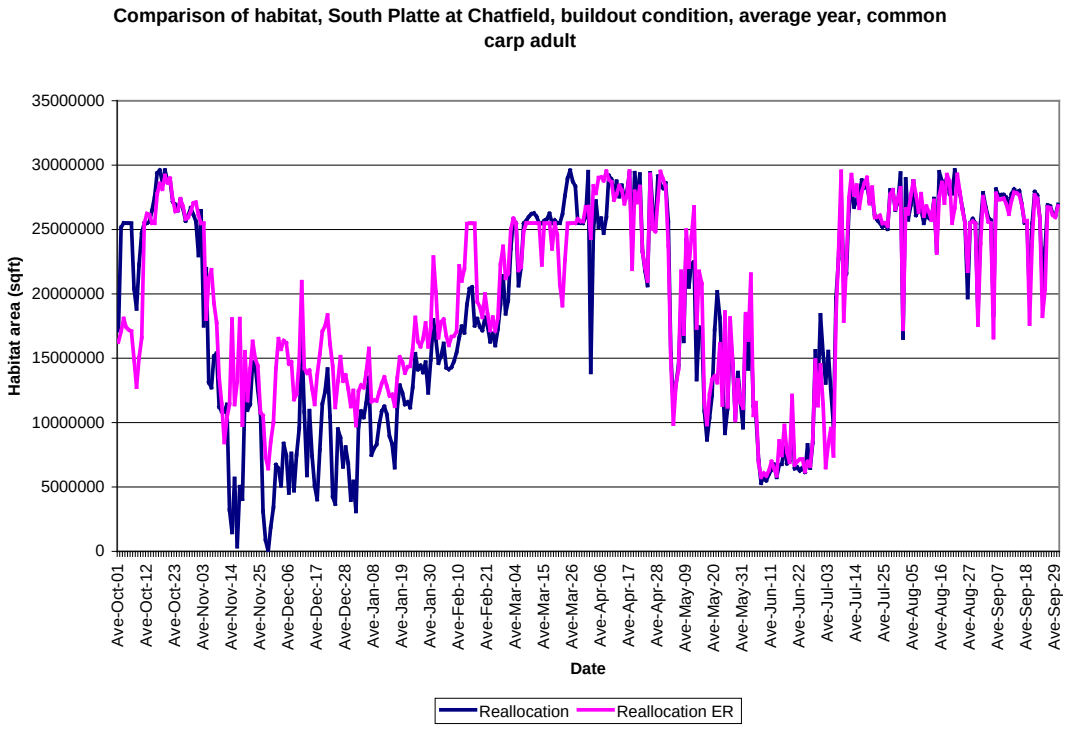


Figure 39. Comparison of habitat area, South Platte at Chatfield, buildout condition, average year, adult common carp.

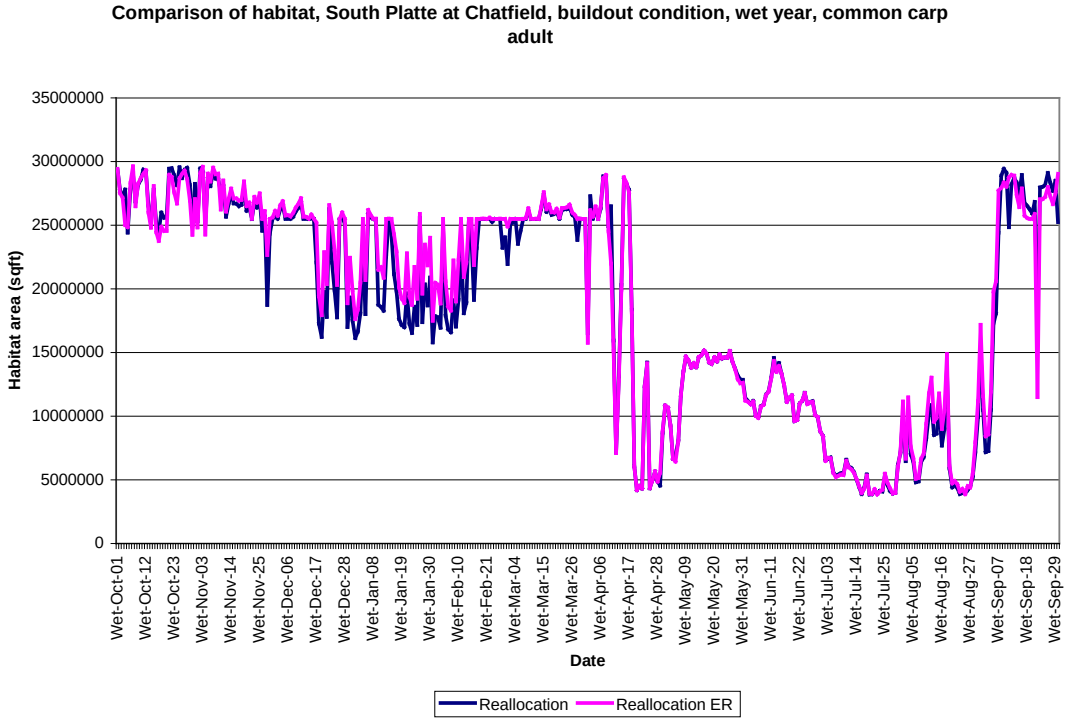


Figure 40. Comparison of habitat area, South Platte at Chatfield, buildout condition, wet year, adult common carp.

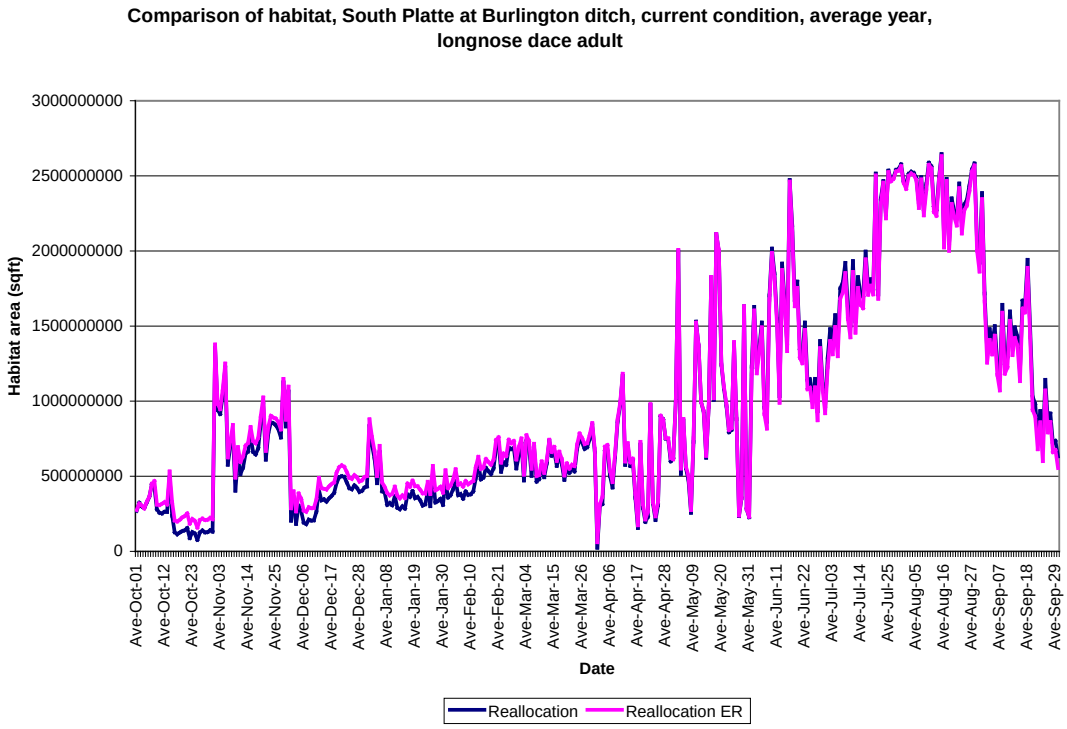


Figure 41. Comparison of habitat area, South Platte at Burlington, current condition, average year, adult longnose dace.

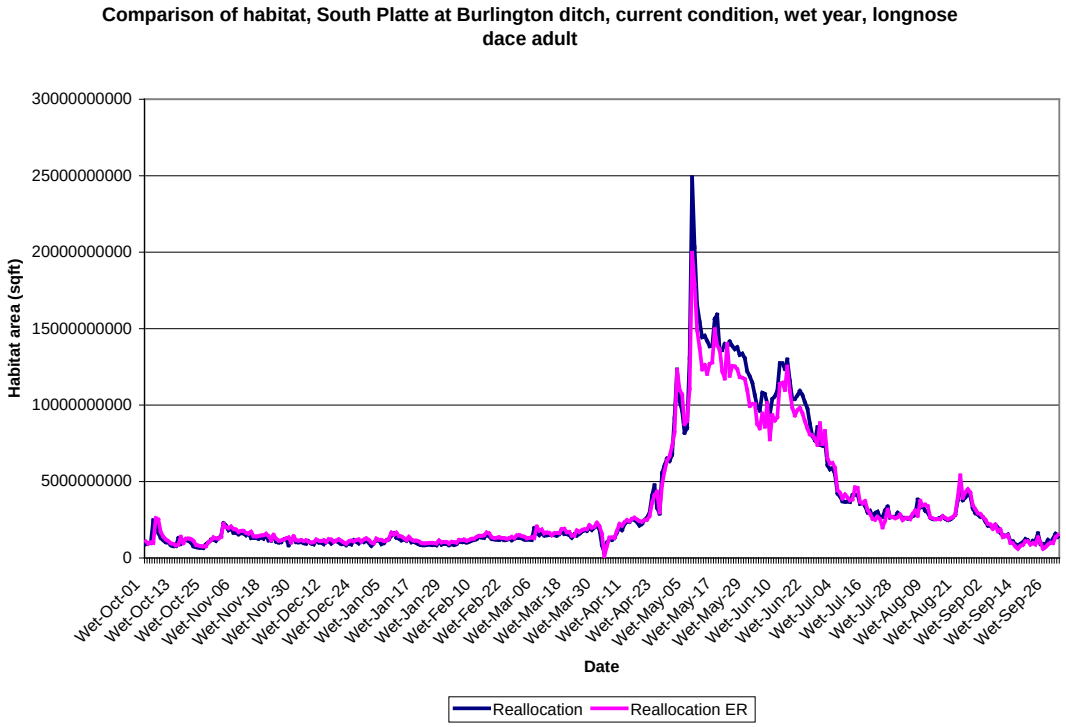


Figure 42. Comparison of habitat area, South Platte at Burlington, current condition, wet year, adult longnose dace.

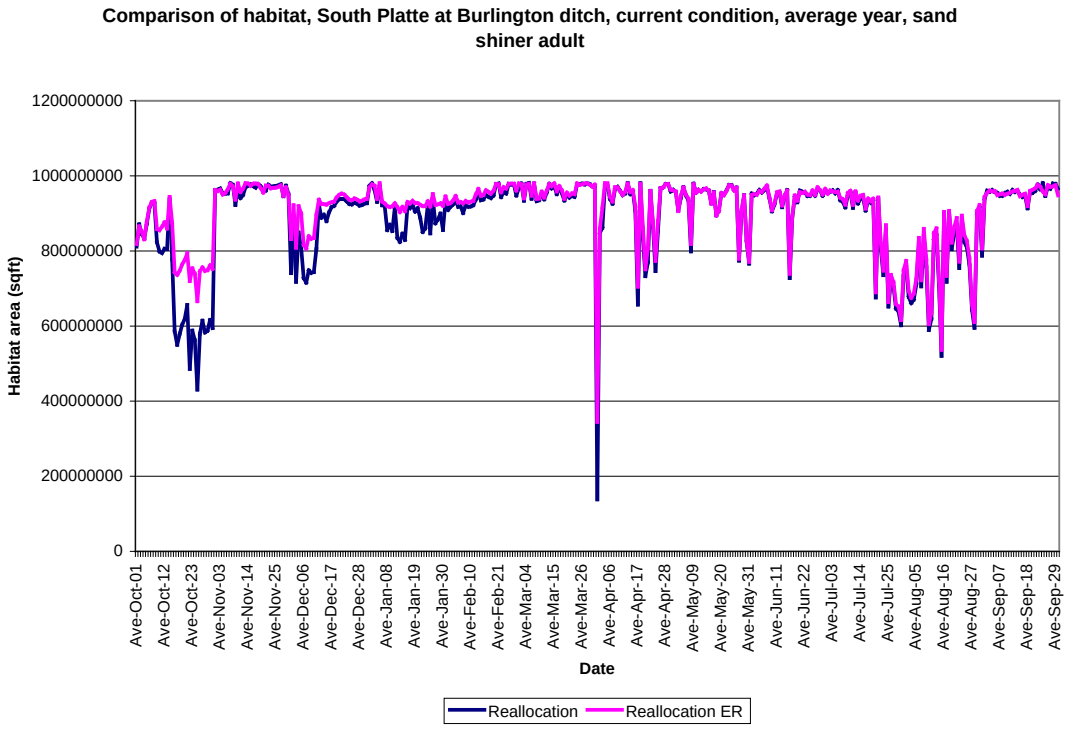


Figure 43. Comparison of habitat area, South Platte at Burlington, current condition, average year, adult sand shiner.

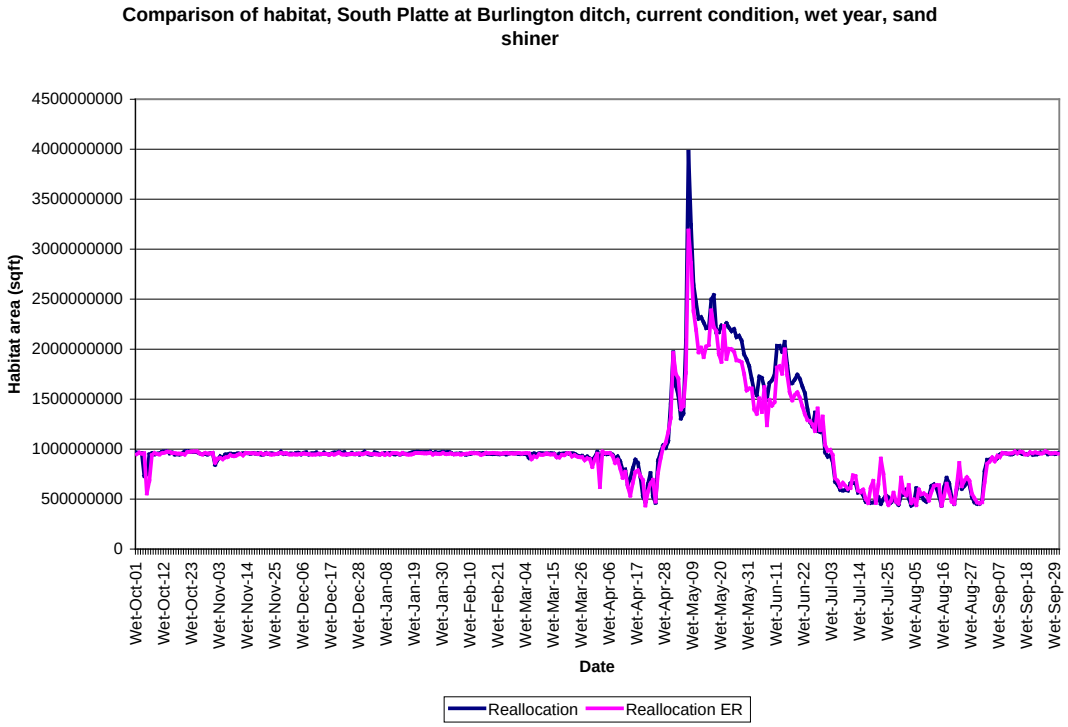


Figure 44. Comparison of habitat area, South Platte at Burlington, current condition, wet year, adult sand shiner.

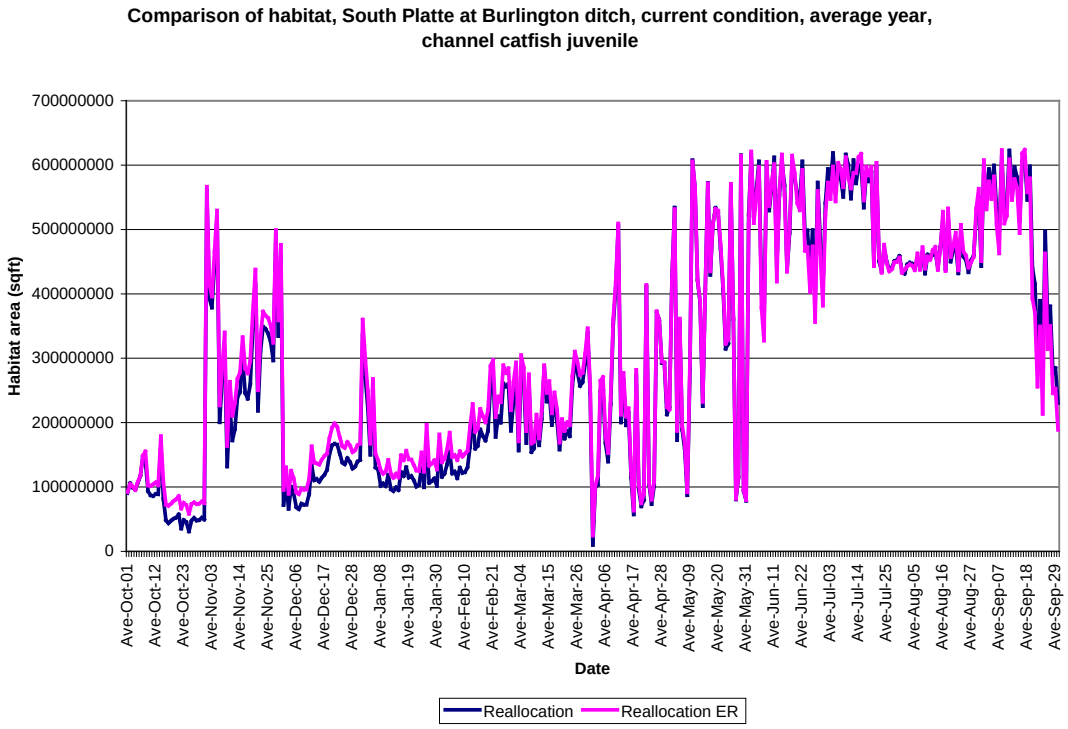


Figure 45. Comparison of habitat area, South Platte at Burlington, current condition, average year, juvenile channel catfish.

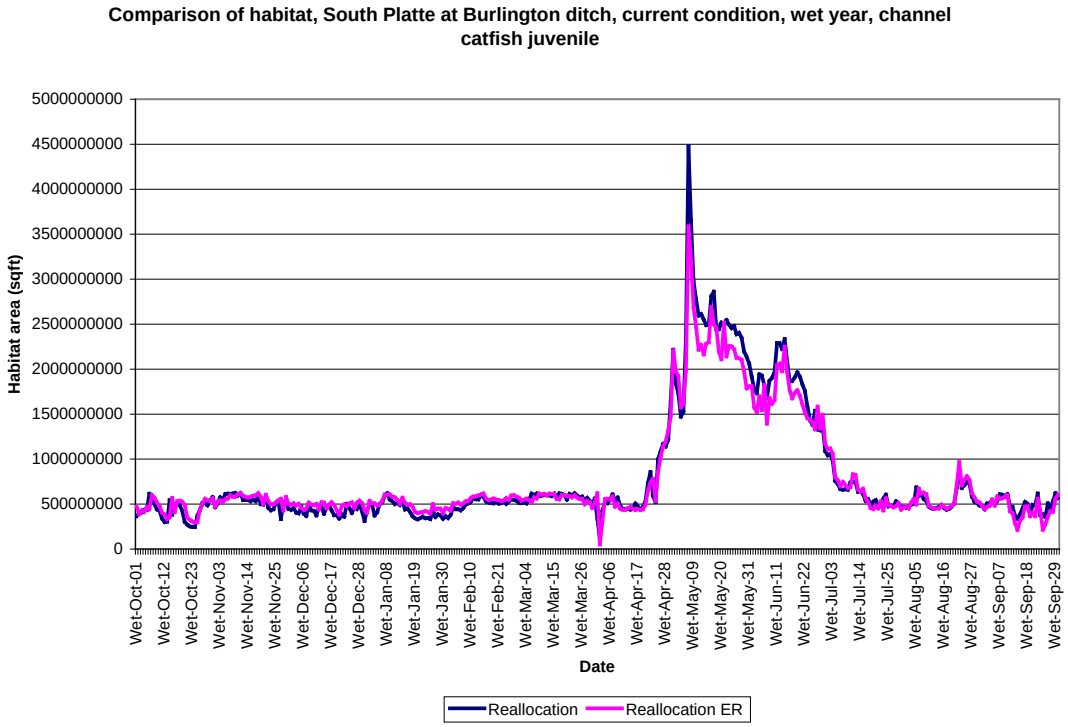


Figure 46. Comparison of habitat area, South Platte at Burlington, current condition, wet year, juvenile channel catfish.

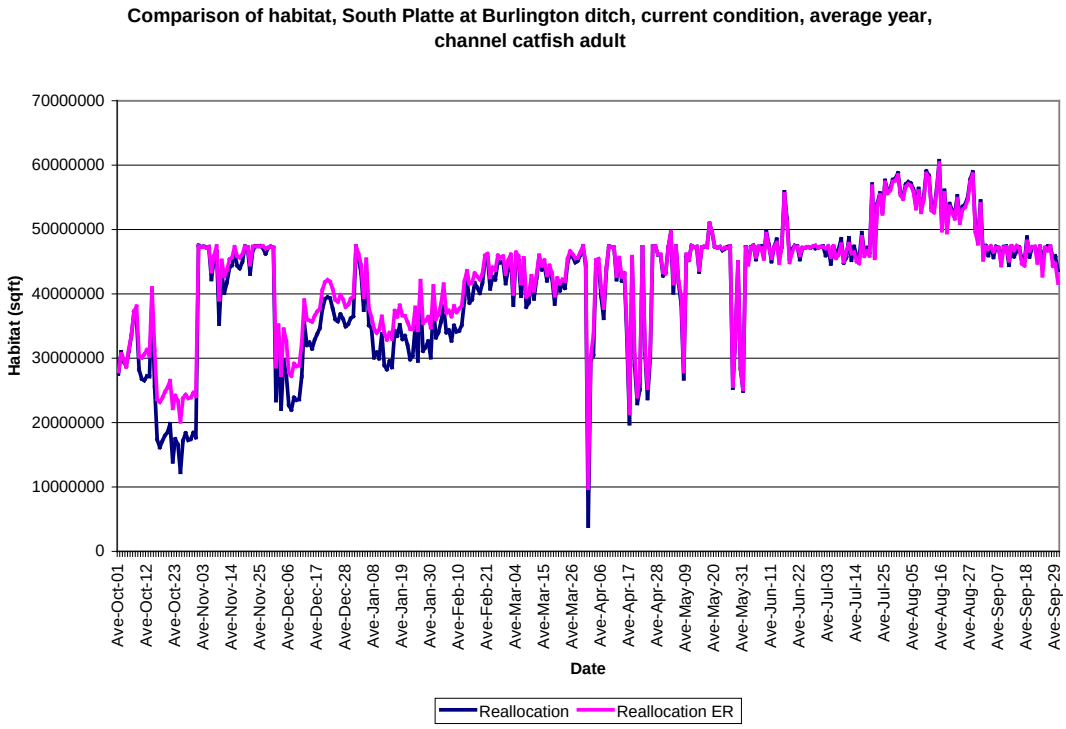


Figure 47. Comparison of habitat area, South Platte at Burlington, current condition, average year, adult channel catfish.

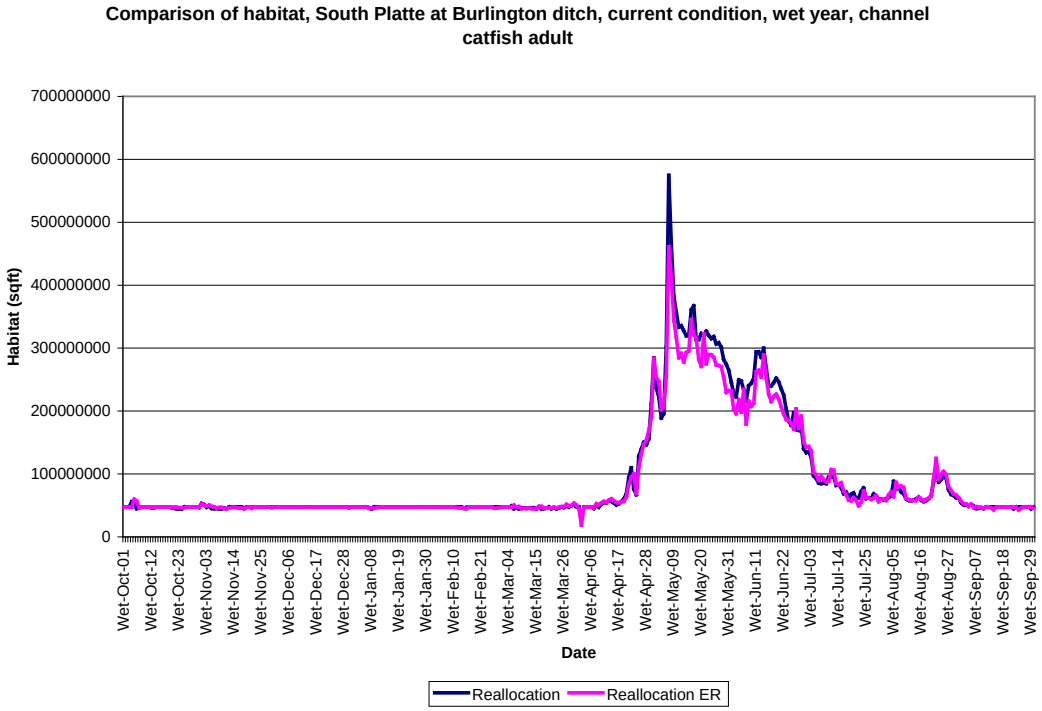


Figure 48. Comparison of habitat area, South Platte at Burlington, current condition, wet year, adult channel catfish.

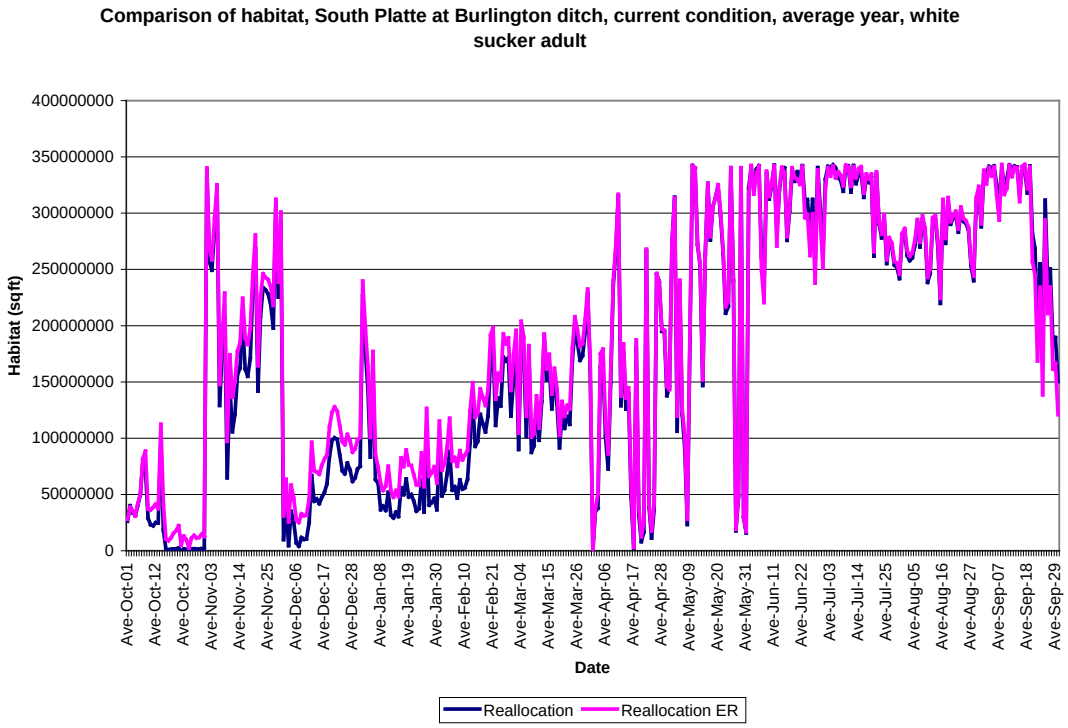


Figure 49. Comparison of habitat area, South Platte at Burlington, current condition, average year, adult white sucker.

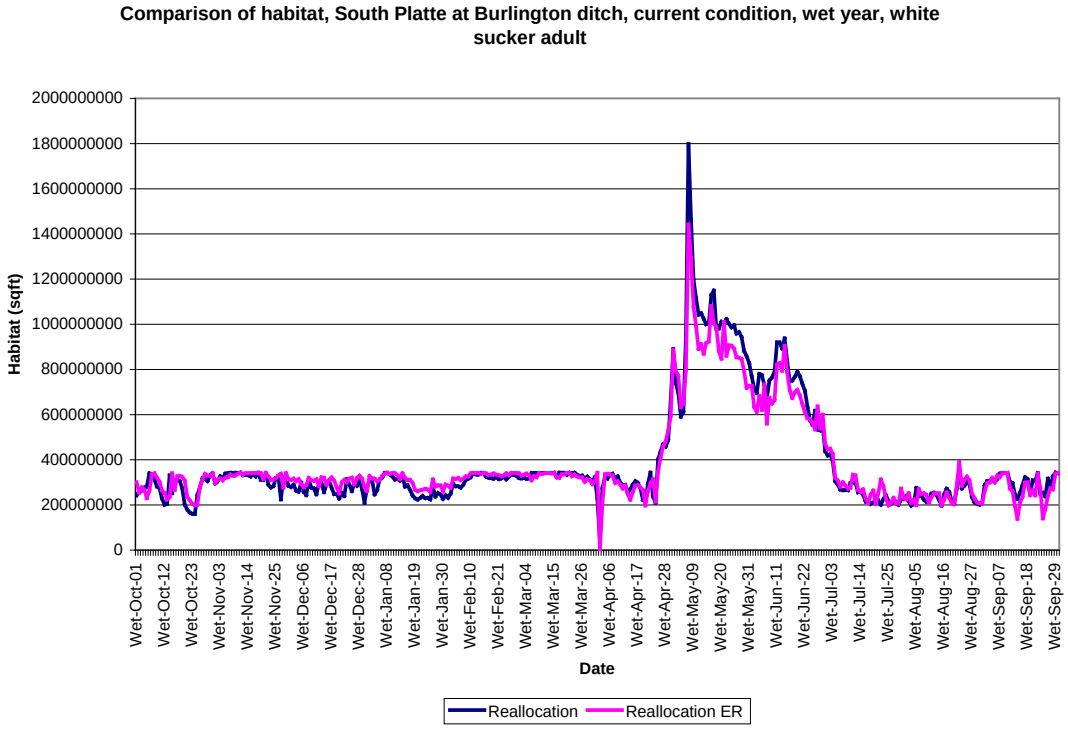


Figure 50. Comparison of habitat area, South Platte at Burlington, current condition, wet year, adult white sucker.

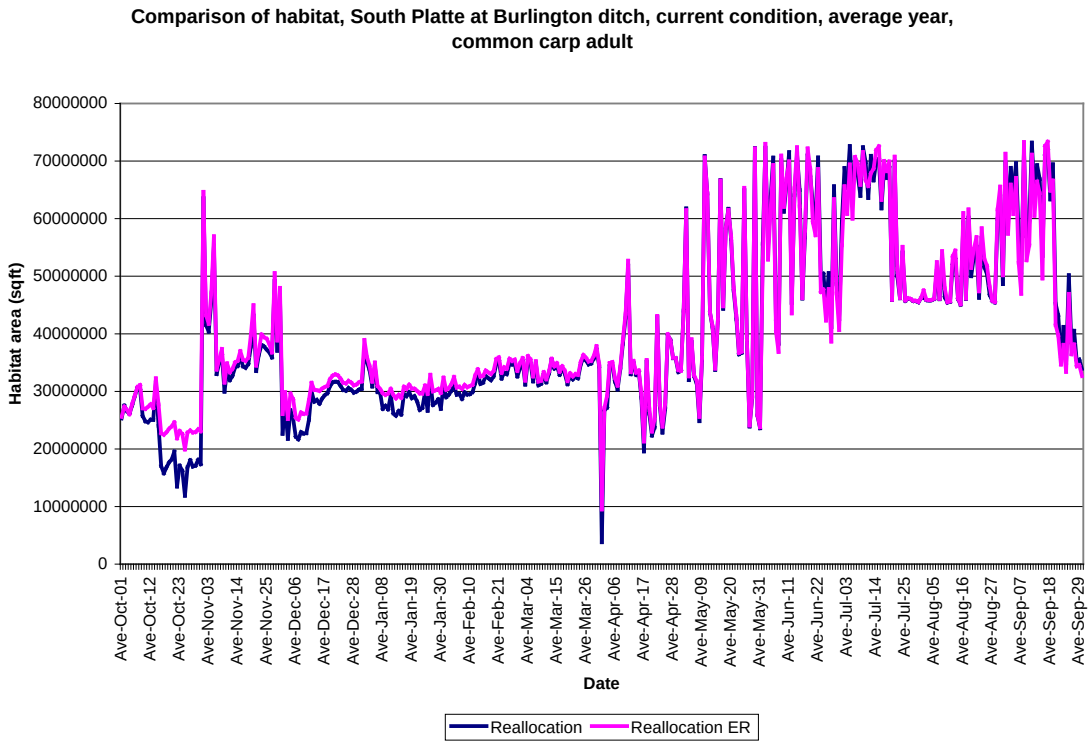


Figure 51. Comparison of habitat area, South Platte at Burlington, current condition, average year, adult common carp.

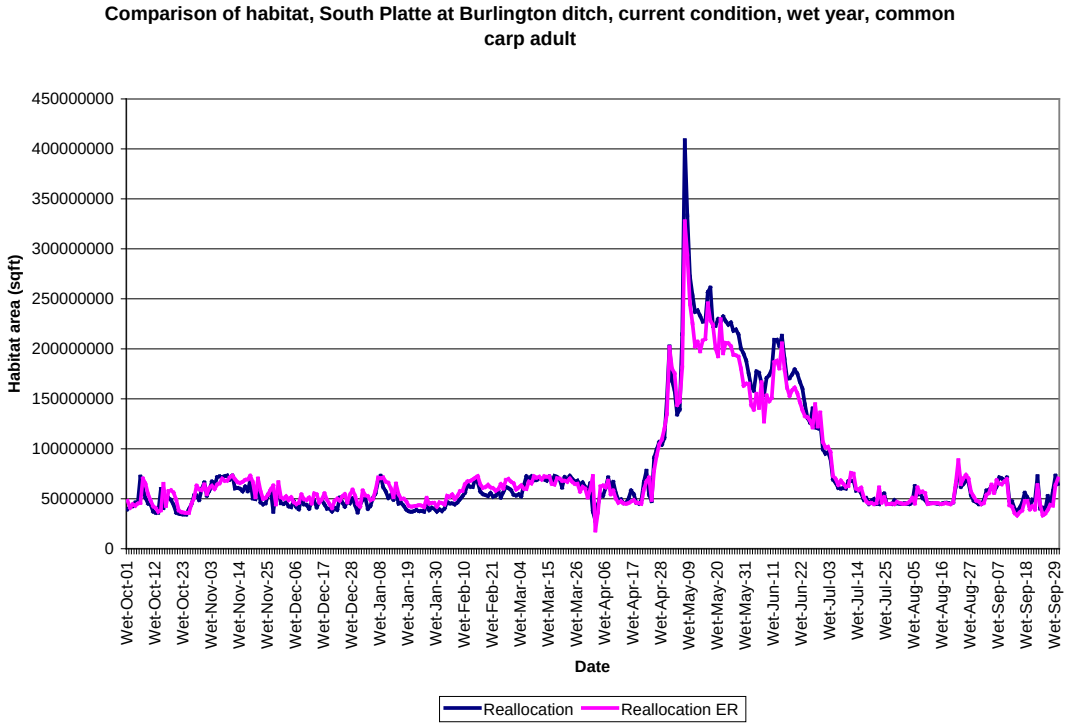


Figure 52. Comparison of habitat area, South Platte at Burlington, current condition, wet year, adult common carp.

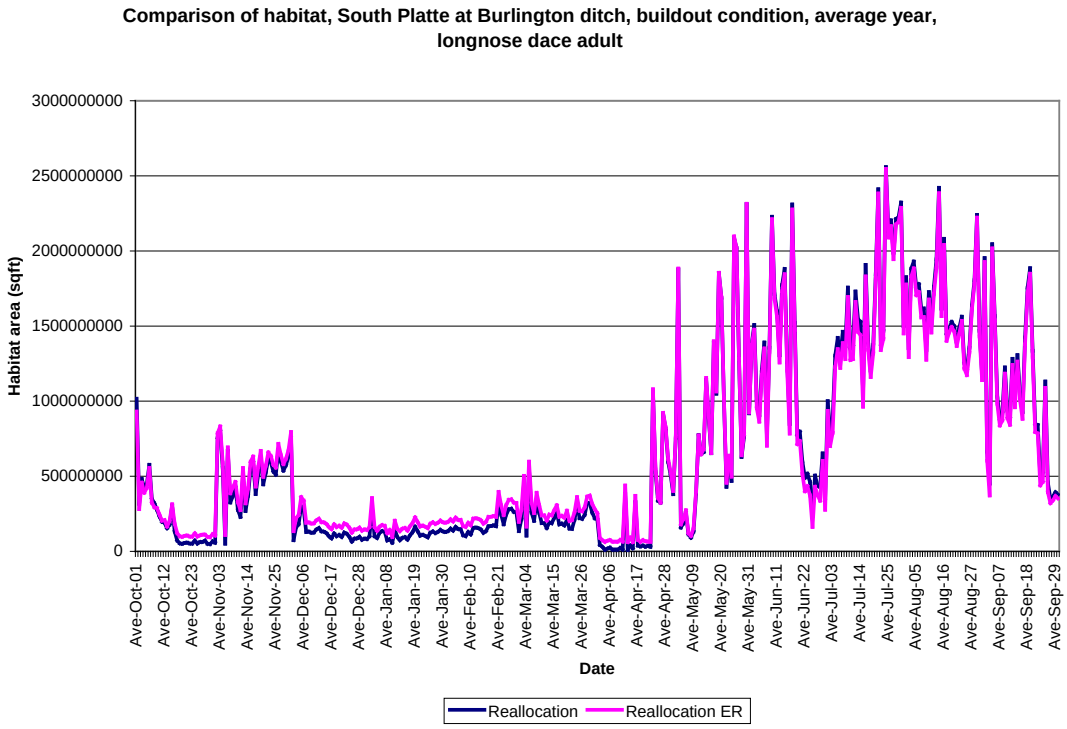


Figure 53. Comparison of habitat area, South Platte at Burlington, buildout condition, average year, adult longnose dace.

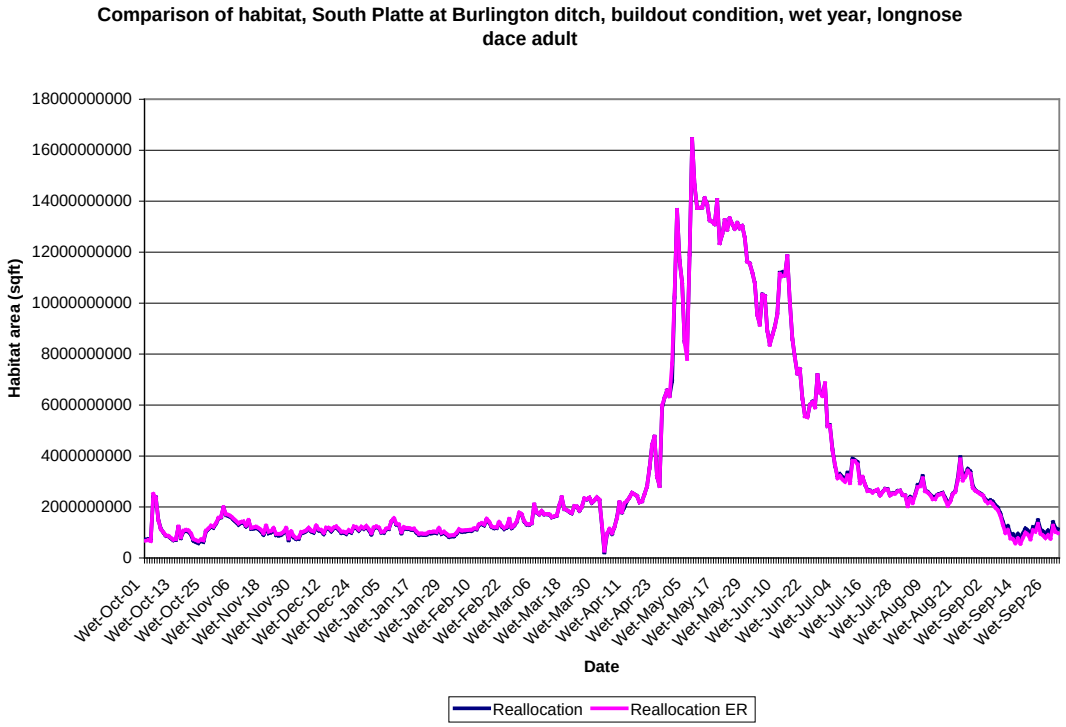


Figure 54. Comparison of habitat area, South Platte at Burlington, buildout condition, wet year, adult longnose dace.

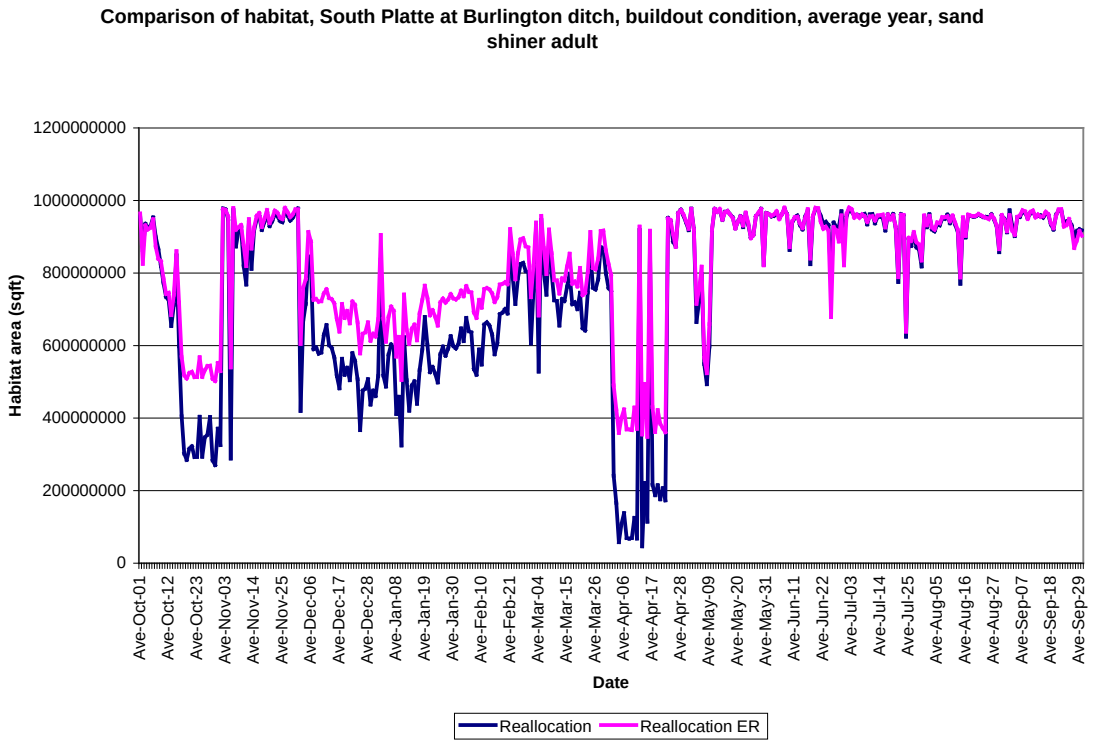


Figure 55. Comparison of habitat area, South Platte at Burlington, buildout condition, average year, adult sand shiner.

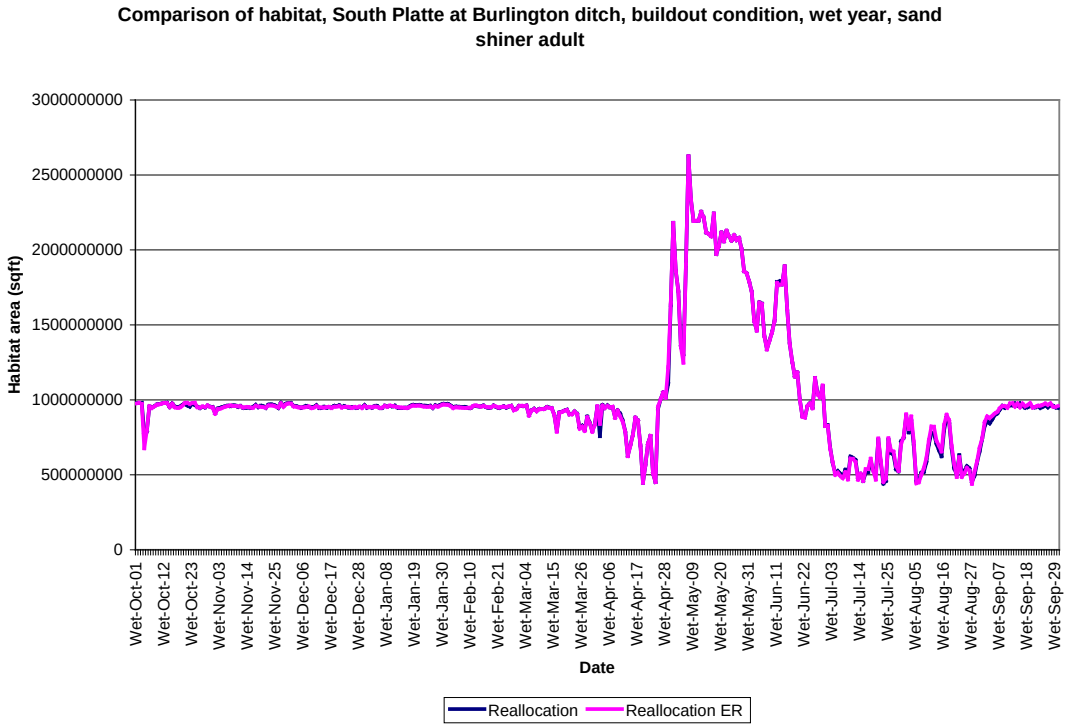


Figure 56. Comparison of habitat area, South Platte at Burlington, buildout condition, wet year, adult sand shiner.

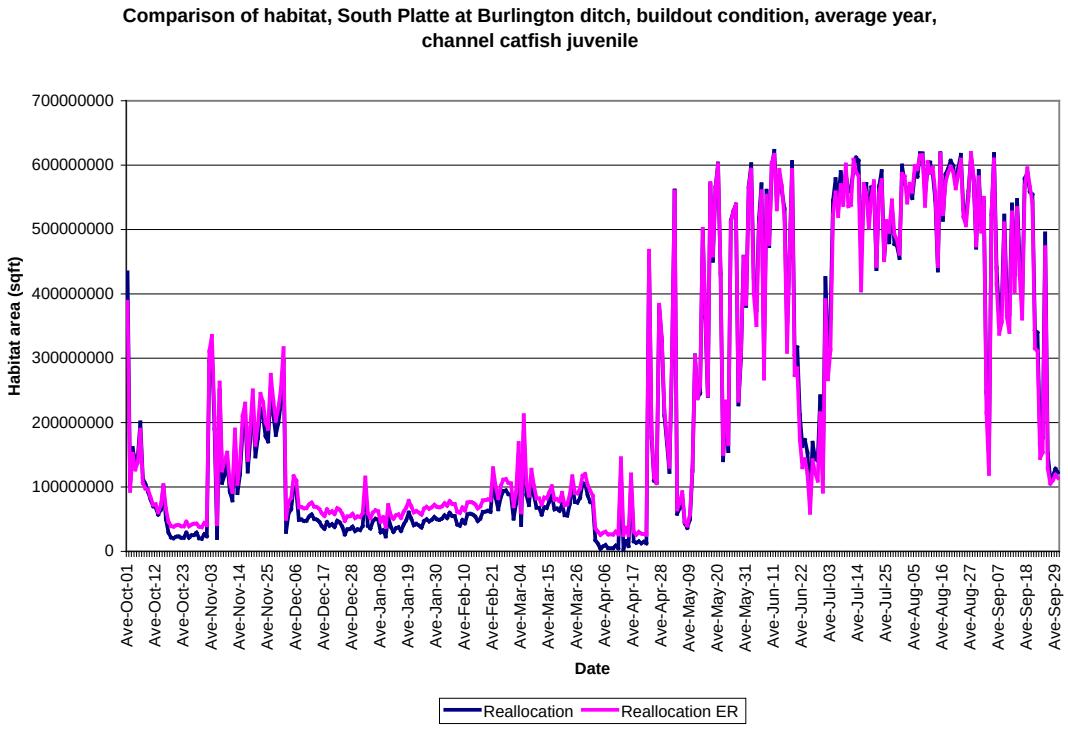


Figure 57. Comparison of habitat area, South Platte at Burlington, buildout condition, average year, juvenile channel catfish.

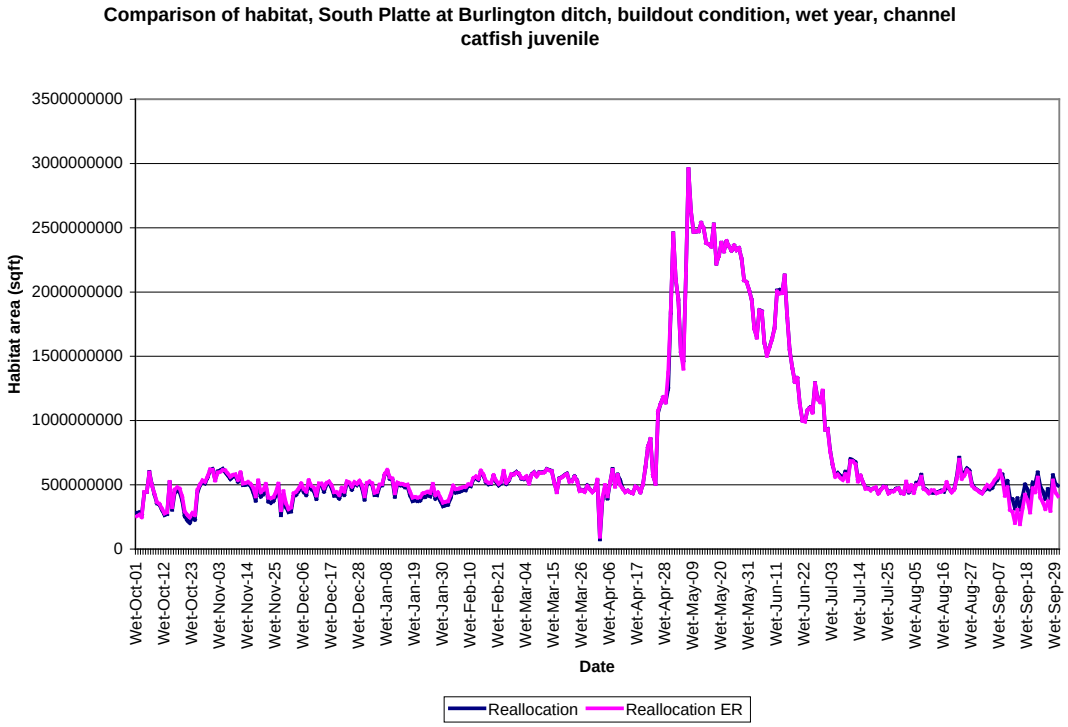


Figure 58. Comparison of habitat area, South Platte at Burlington, buildout condition, wet year, juvenile channel catfish.

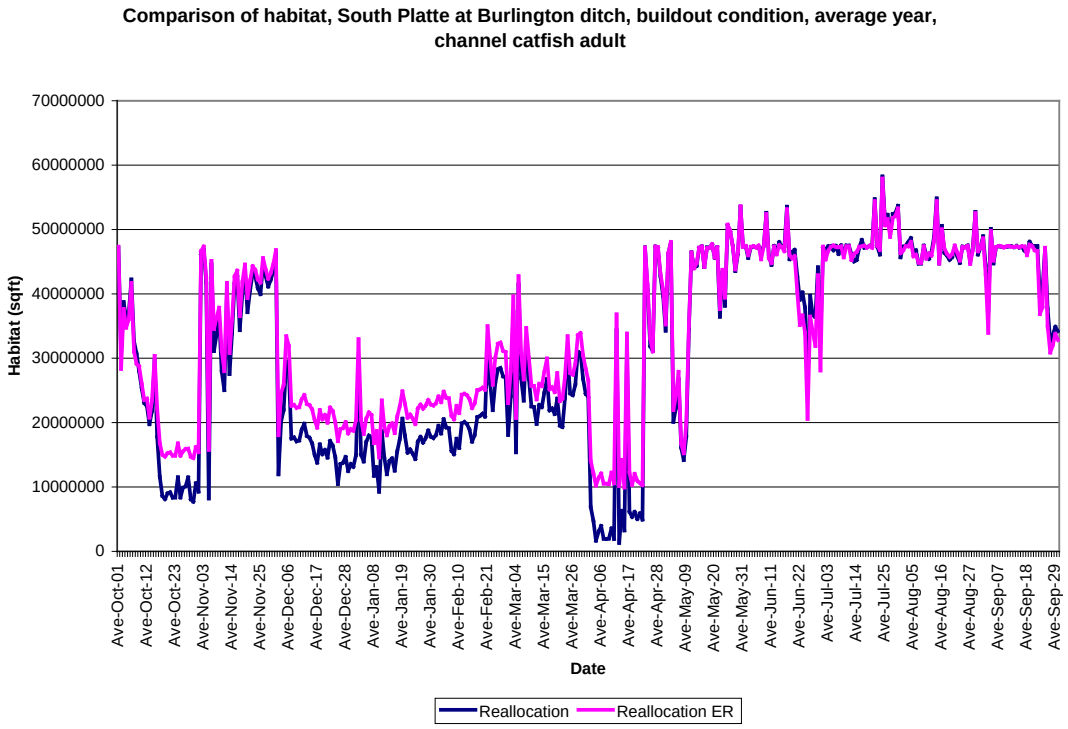


Figure 59. Comparison of habitat area, South Platte at Burlington, buildout condition, average year, adult channel catfish.

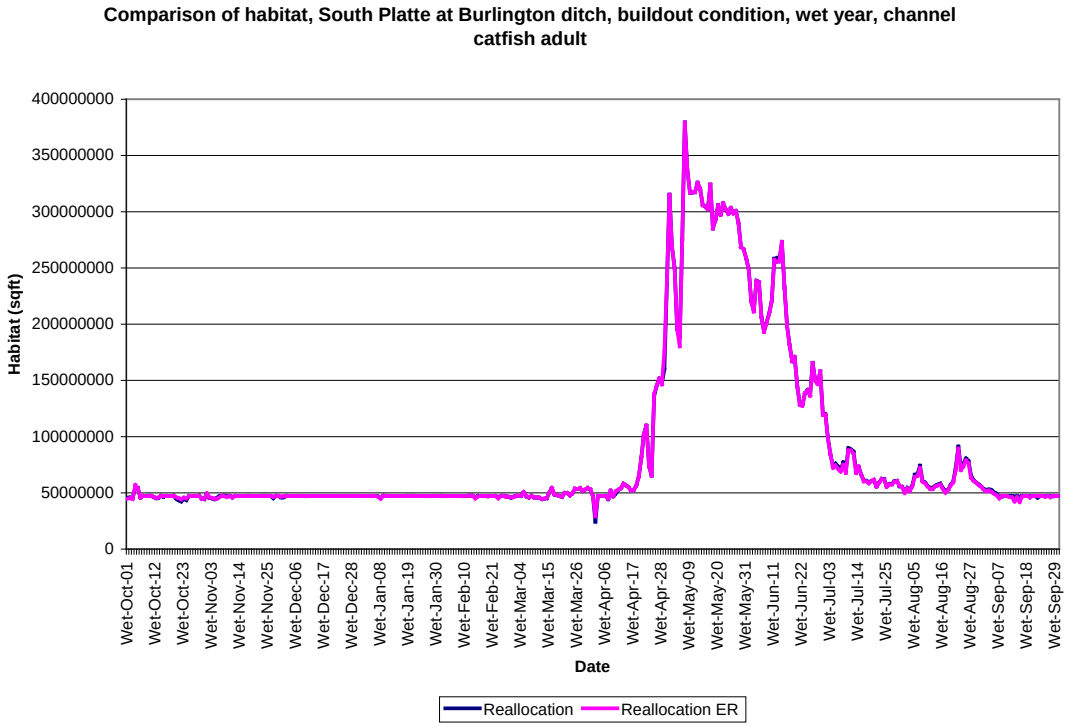


Figure 60. Comparison of habitat area, South Platte at Burlington, buildout condition, wet year, adult channel catfish.

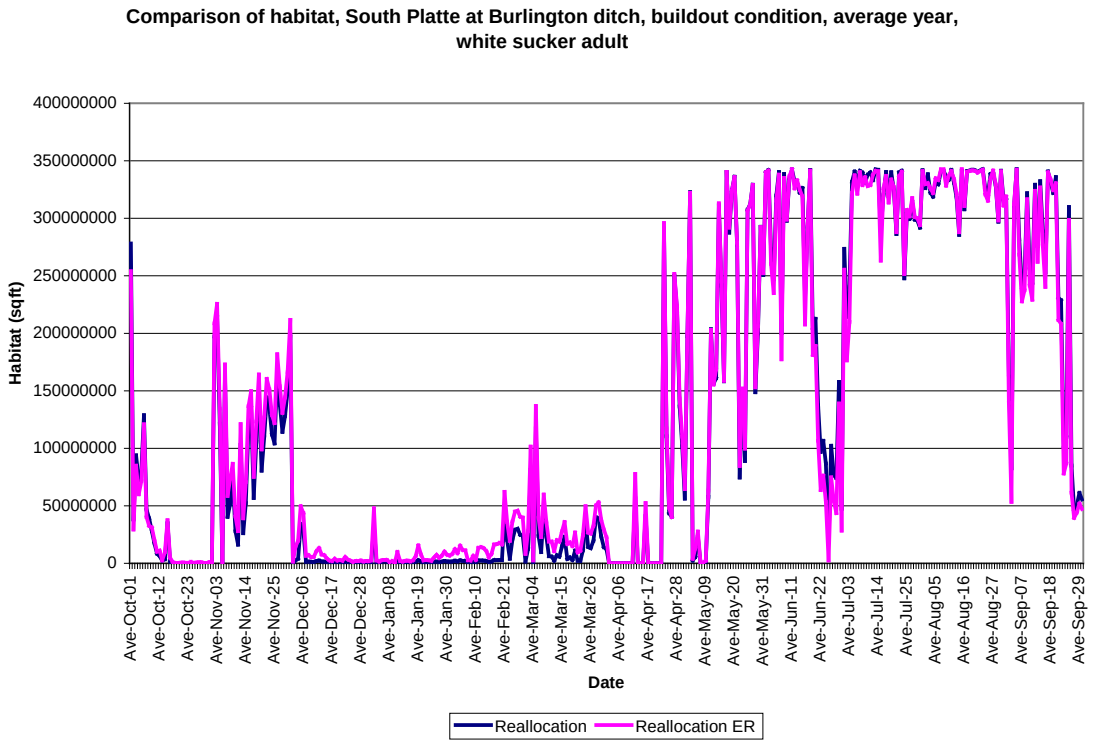


Figure 61. Comparison of habitat area, South Platte at Burlington, buildout condition, average year, adult white sucker.

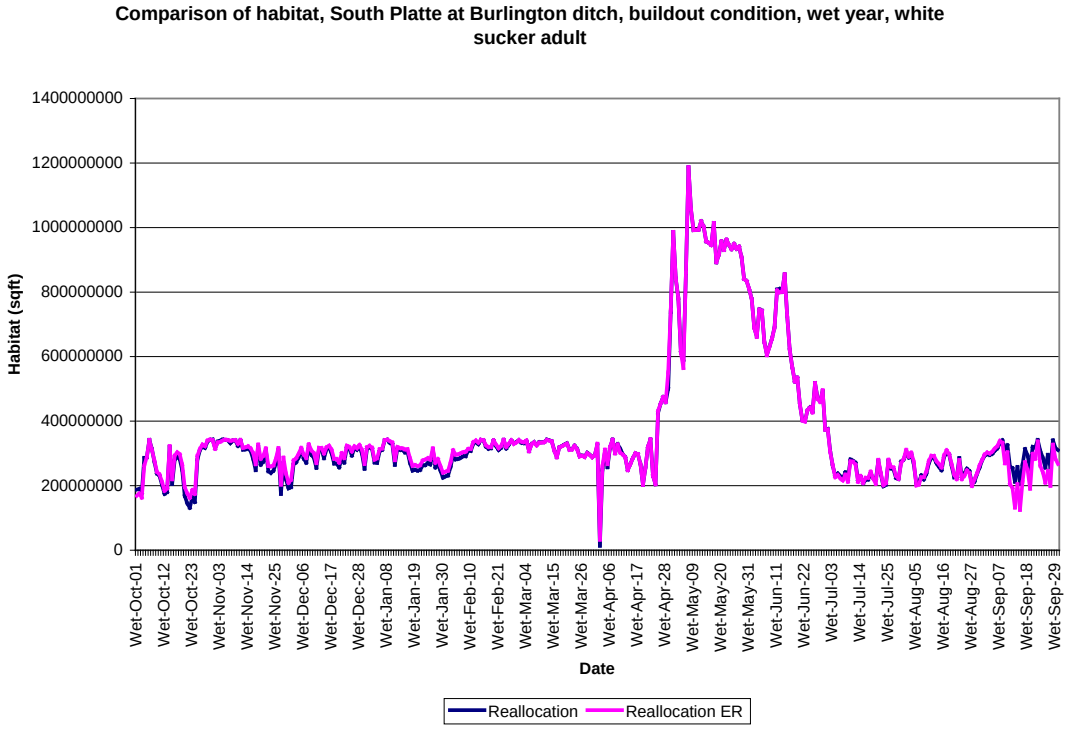


Figure 62. Comparison of habitat area, South Platte at Burlington, buildout condition, wet year, adult white sucker.

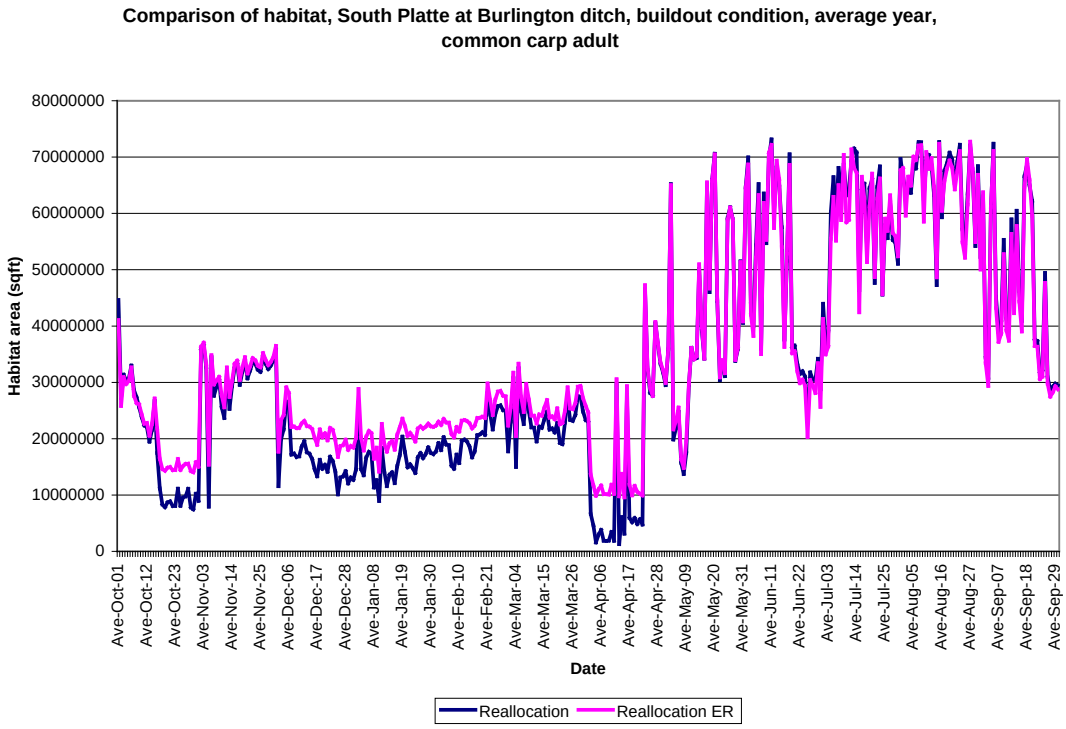


Figure 63. Comparison of habitat area, South Platte at Burlington, buildout condition, average year, adult common carp.

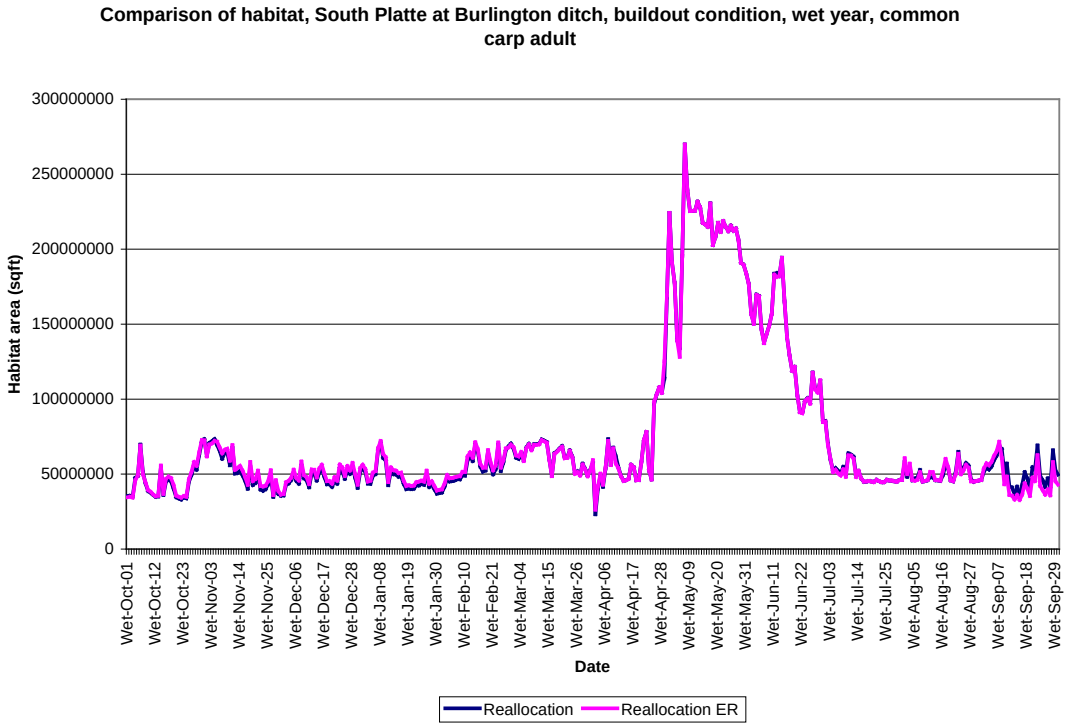


Figure 64. Comparison of habitat area, South Platte at Burlington, buildout condition, wet year, adult common carp.

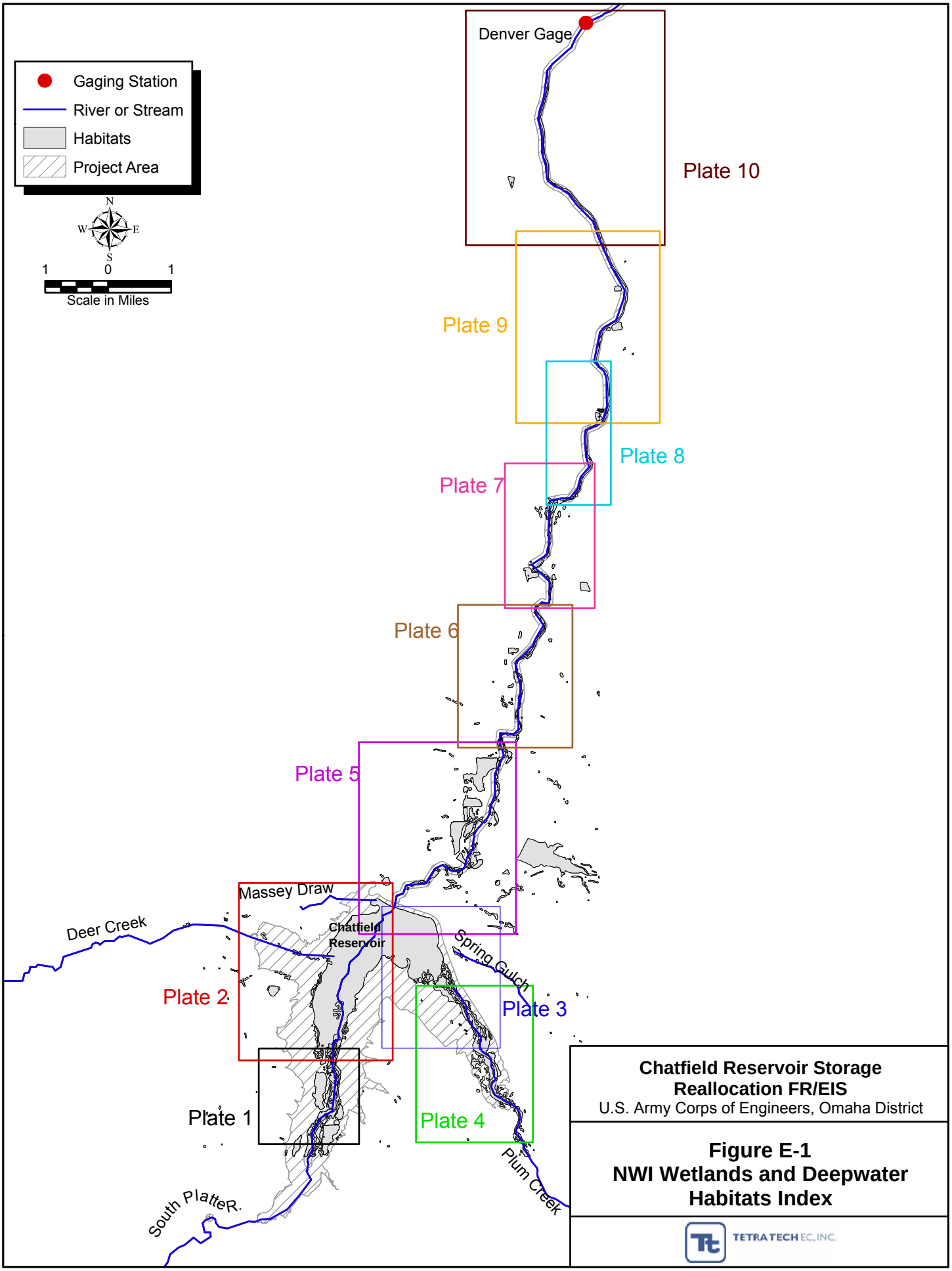
Appendix E
Wetlands

Wetland Classification Indicators and Their Definition

NWI Code	Definition
Lacustrine System	
L1UBH	Lacustrine, limnetic, unconsolidated bottom, permanently flooded
L1UBHh	Lacustrine, limnetic, unconsolidated bottom, permanently flooded, diked/impounded
L1UBHx	Lacustrine, limnetic, unconsolidated bottom, permanently flooded, excavated
L2ABG	Lacustrine, littoral, aquatic bed, intermittently exposed
L2ABGh	Lacustrine, littoral, aquatic bed, intermittently exposed, diked/impounded
L2USA	Lacustrine, littoral, unconsolidated shore, temporarily flooded
L2USC	Lacustrine, littoral, unconsolidated shore, seasonally flooded
L2USCh	Lacustrine, littoral, unconsolidated shore, seasonally flooded, diked/impounded
Palustrine System	
PABF	Palustrine, aquatic bed, semi-permanently flooded
PABFh	Palustrine, aquatic bed, semi-permanently flooded, diked/impounded
PABFx	Palustrine, aquatic bed, semi-permanently flooded, excavated
PABGh	Palustrine, aquatic bed, intermittently exposed, diked/impounded
PABGx	Palustrine, aquatic bed, intermittently exposed, excavated
PEMA	Palustrine, emergent wetland persistent, temporarily flooded
PEMAd	Palustrine, emergent wetland persistent, temporarily flooded, intermittently exposed
PEMAh	Palustrine, emergent wetland persistent, temporarily flooded, diked/impounded
PEMAx	Palustrine, emergent wetland persistent, temporarily flooded, excavated
PEMB	Palustrine, emergent wetland persistent, saturated
PEMC	Palustrine, emergent wetland persistent, seasonally flooded
PEMCh	Palustrine, emergent wetland persistent, seasonally flooded, diked/impounded
PEMCx	Palustrine, emergent wetland persistent, seasonally flooded, excavated
PEMF	Palustrine, emergent wetland persistent, semi-permanently flooded
PEMFd	Palustrine, emergent wetland persistent, semi-permanently flooded, intermittently exposed
PEMFh	Palustrine, emergent wetland persistent, semi-permanently flooded, diked/impounded
PEMFx	Palustrine, emergent wetland persistent, semi-permanently flooded, excavated
PFOA	Palustrine, forested wetland, temporarily flooded
PFOAh	Palustrine, forested wetland, temporarily flooded, diked/impounded
PFOAx	Palustrine, forested wetland, temporarily flooded, excavated
PFOHh	Palustrine, forested wetland, permanently flooded, diked/impounded
PSSA	Palustrine, scrub/shrub wetland, temporarily flooded
PSSAh	Palustrine, scrub/shrub wetland, temporarily flooded, diked/impounded
PSSAx	Palustrine, scrub/shrub wetland, temporarily flooded, excavated
PSSB	Palustrine, scrub/shrub wetland, saturated
PSSC	Palustrine, scrub-shrub wetland, seasonally flooded
PSSCh	Palustrine, scrub-shrub wetland, seasonally flooded, diked/impounded
PUBFx	Palustrine, unconsolidated bottom, semi-permanently flooded, excavated
PUBGx	Palustrine, unconsolidated bottom, intermittently exposed, excavated
PUSAx	Palustrine, unconsolidated shore, temporarily flooded, excavated
PUSC	Palustrine, unconsolidated shore, seasonally flooded
PUSCh	Palustrine, unconsolidated shore, seasonally flooded, diked/impounded
PUSCx	Palustrine, unconsolidated shore, seasonally flooded, excavated

Wetland Classification Indicators and Their Definition

Riverine System	
R2UBG	Riverine, lower perennial, unconsolidated bottom, intermittently exposed
R2UBH	Riverine, lower perennial, unconsolidated bottom, permanently flooded
R2USA	Riverine, lower perennial, Unconsolidated shore, temporarily flooded
R2USC	Riverine, lower perennial, unconsolidated shore, seasonally flooded
R3UBH	Riverine, upper perennial, unconsolidated bottom, permanently flooded
R3USA	Riverine, upper perennial, unconsolidated shore, temporarily flooded
R3USC	Riverine, upper perennial, unconsolidated shore, seasonally flooded



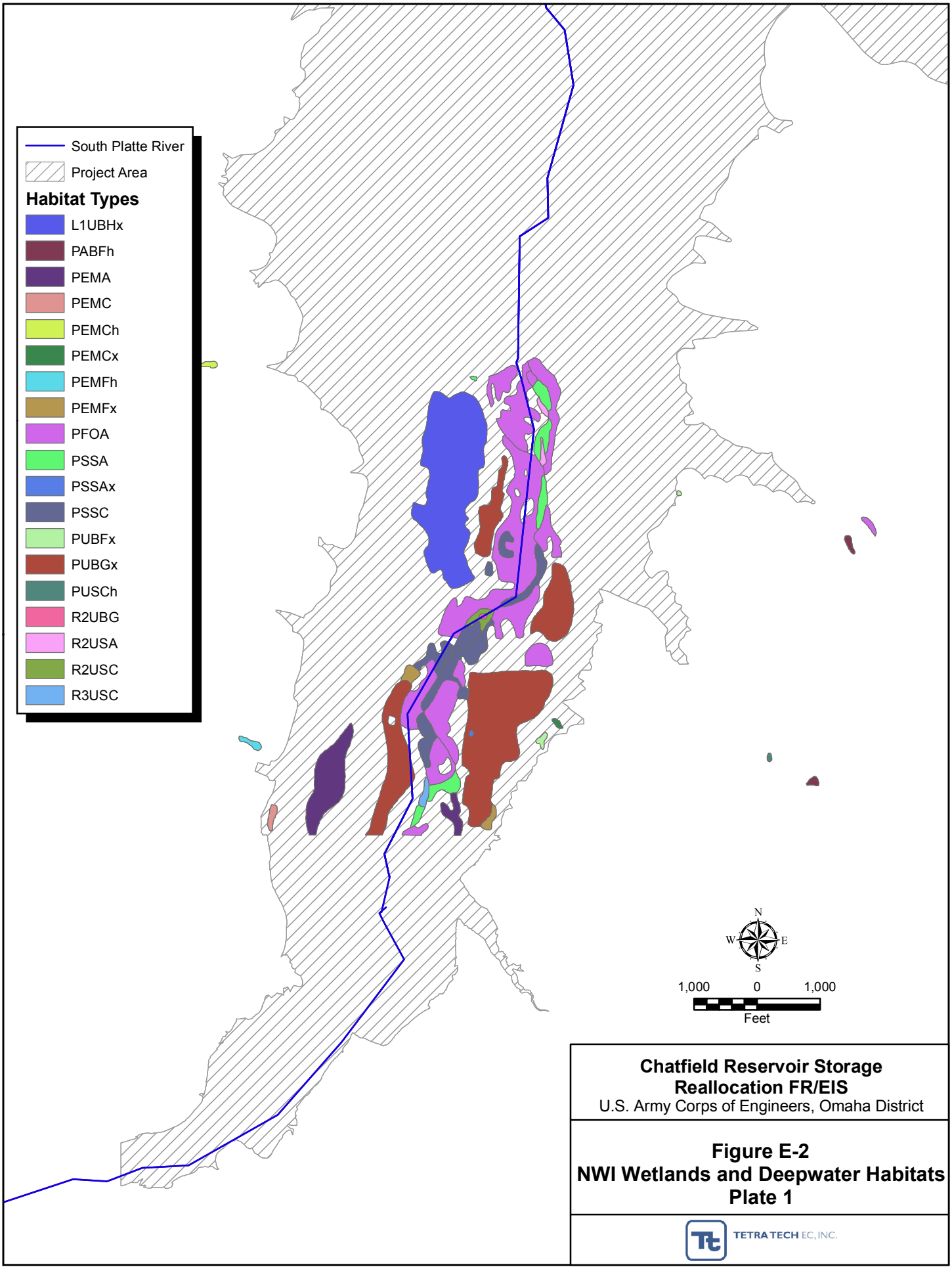
Chatfield Reservoir Storage Reallocation FR/EIS

U.S. Army Corps of Engineers, Omaha District

Figure E-1
NWI Wetlands and Deepwater Habitats Index

TETRA TECH EC, INC.

03/10/2006 J:\Chatfield_USACE\GIS\Figures\FigureA-1.mxd TtEC-Lakewood kdc



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U.S. Army Corps of Engineers, Omaha District

Figure E-2
NWI Wetlands and Deepwater Habitats
Plate 1

TETRA TECH EC, INC.

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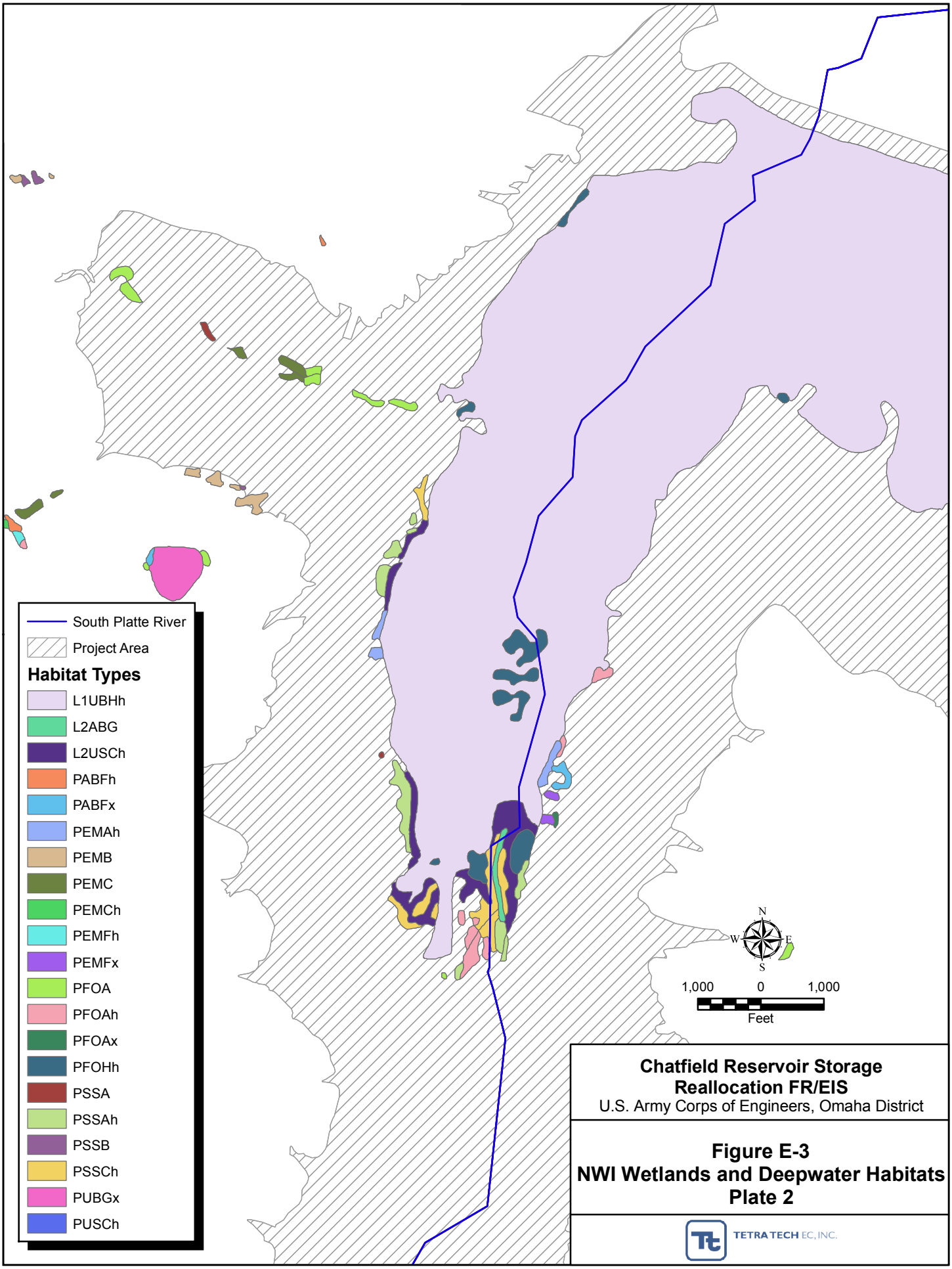

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U.S. Army Corps of Engineers, Omaha District

Figure E-3
NWI Wetlands and Deepwater Habitats
Plate 2

TETRA TECH EC, INC.

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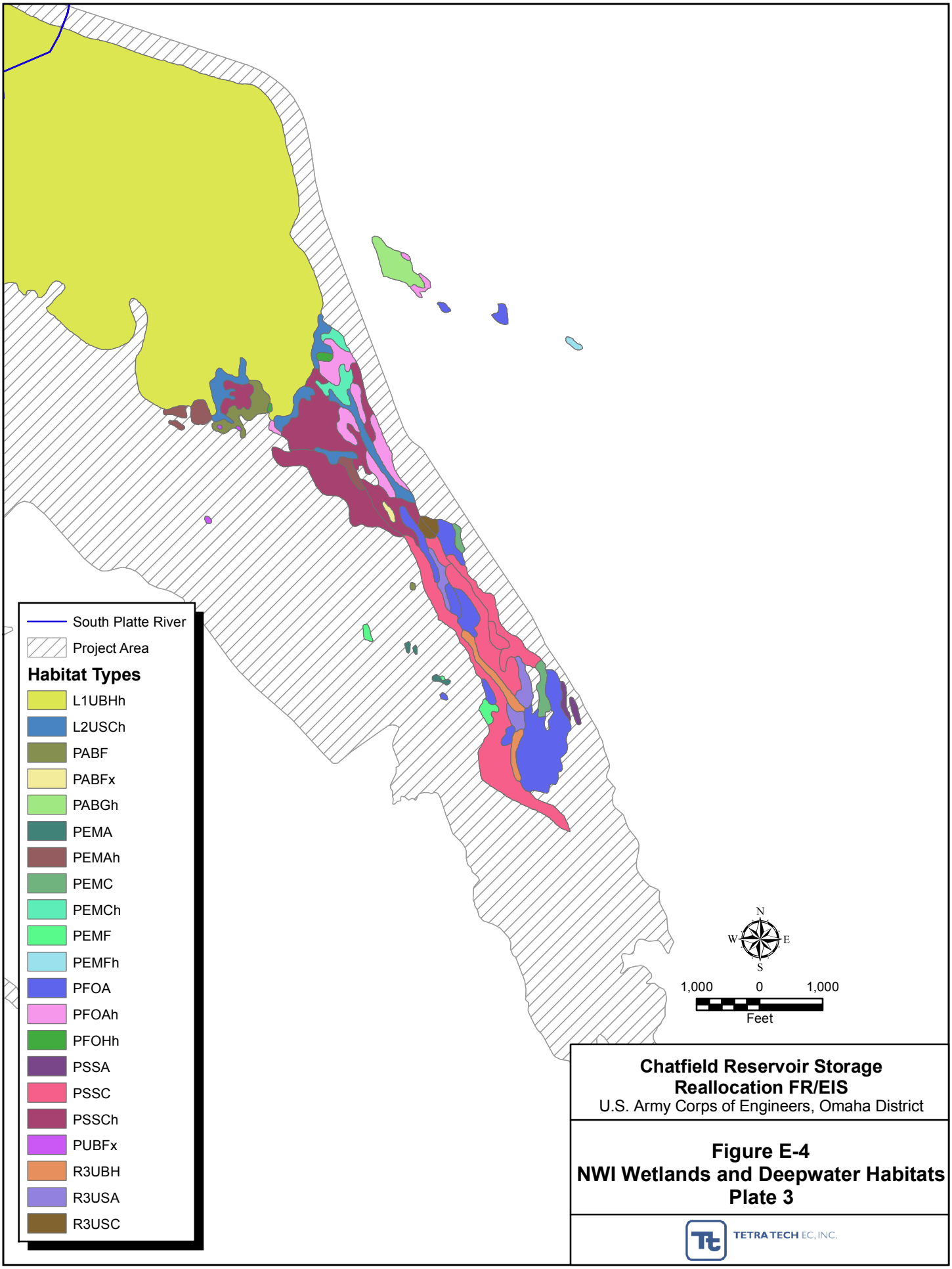

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U.S. Army Corps of Engineers, Omaha District

Figure E-4
NWI Wetlands and Deepwater Habitats
Plate 3

TETRA TECH EC, INC.

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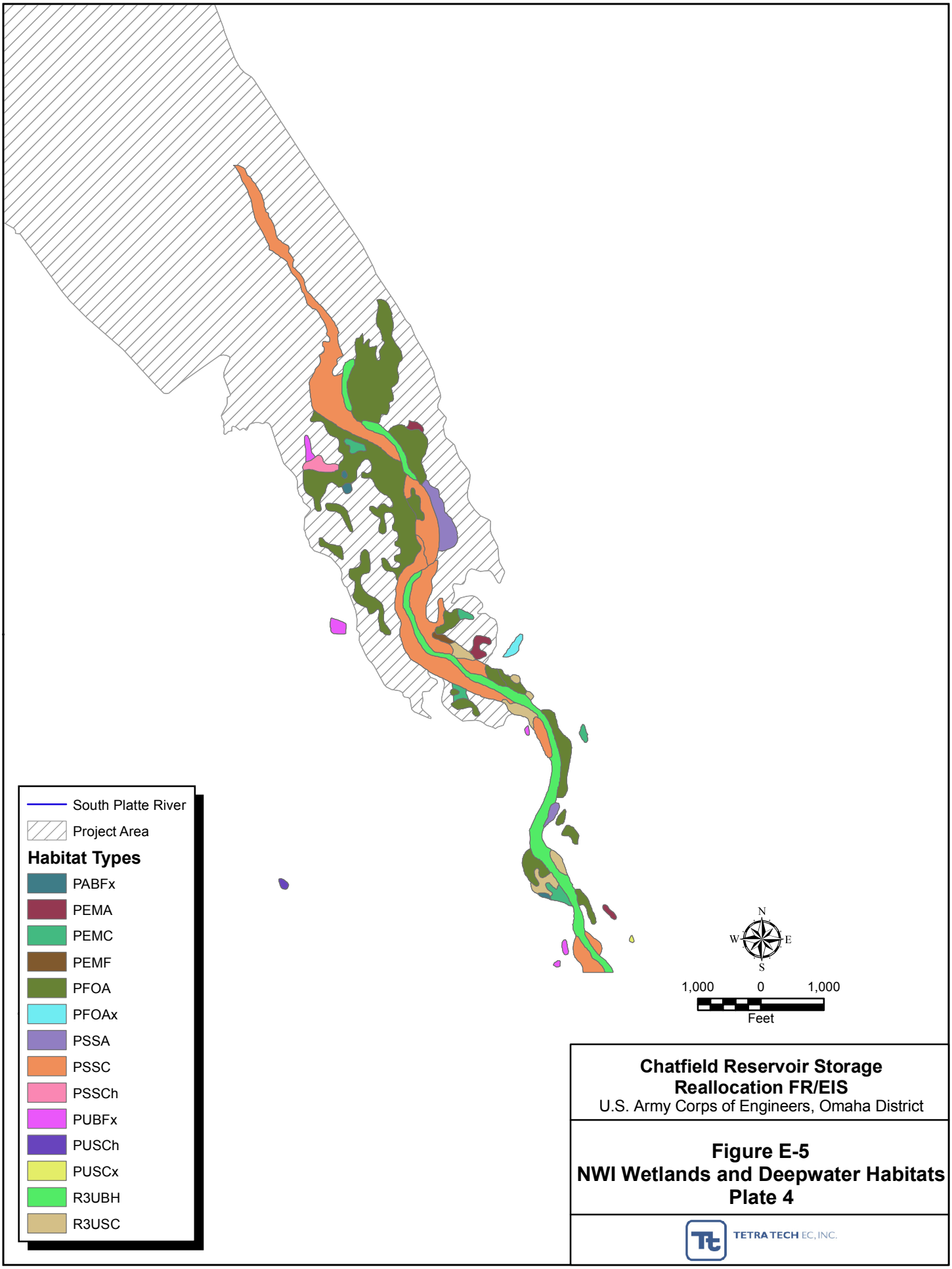

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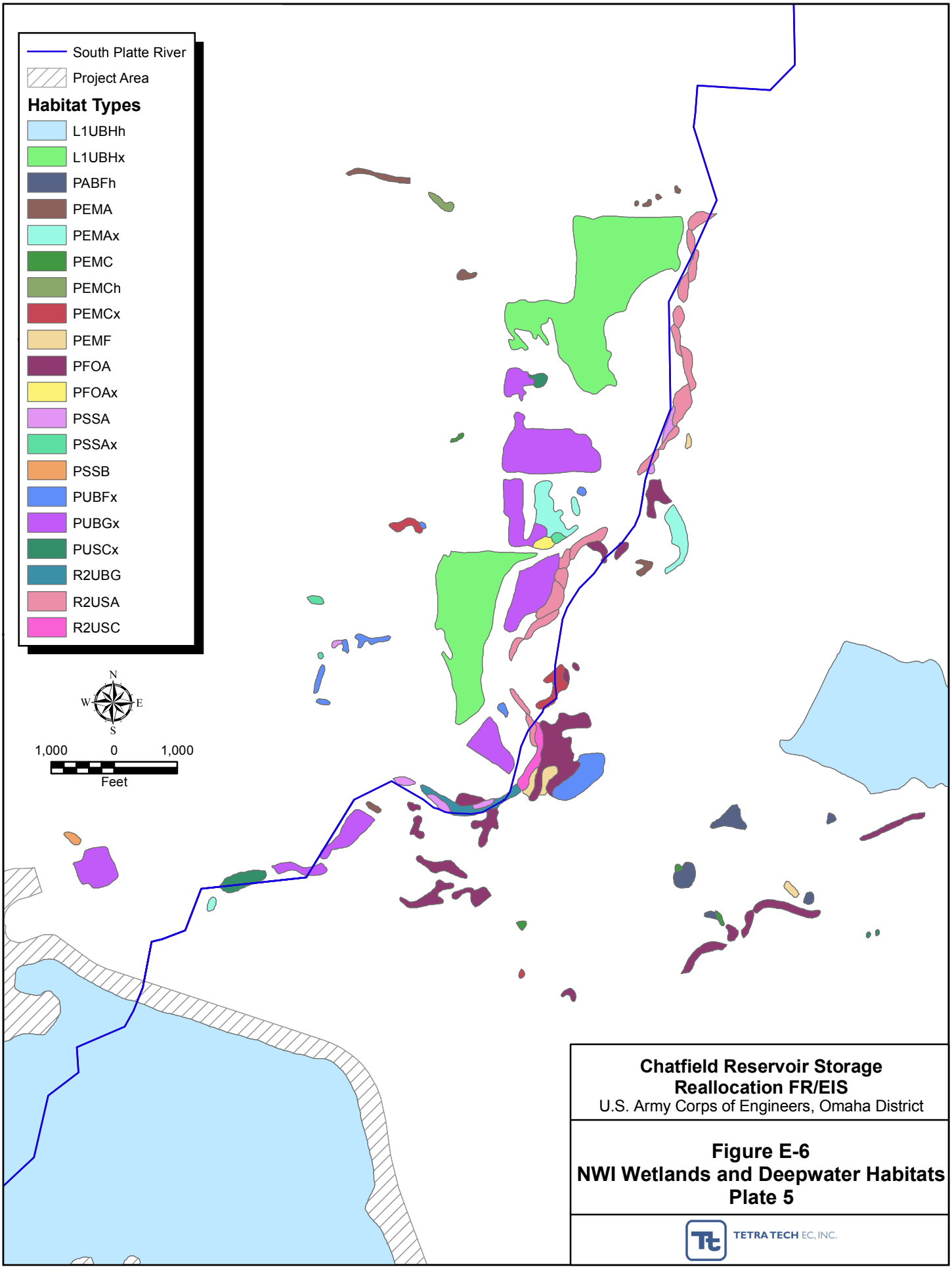

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Figure E-6
NWI Wetlands and Deepwater Habitats
Plate 5

TETRA TECH EC, INC.

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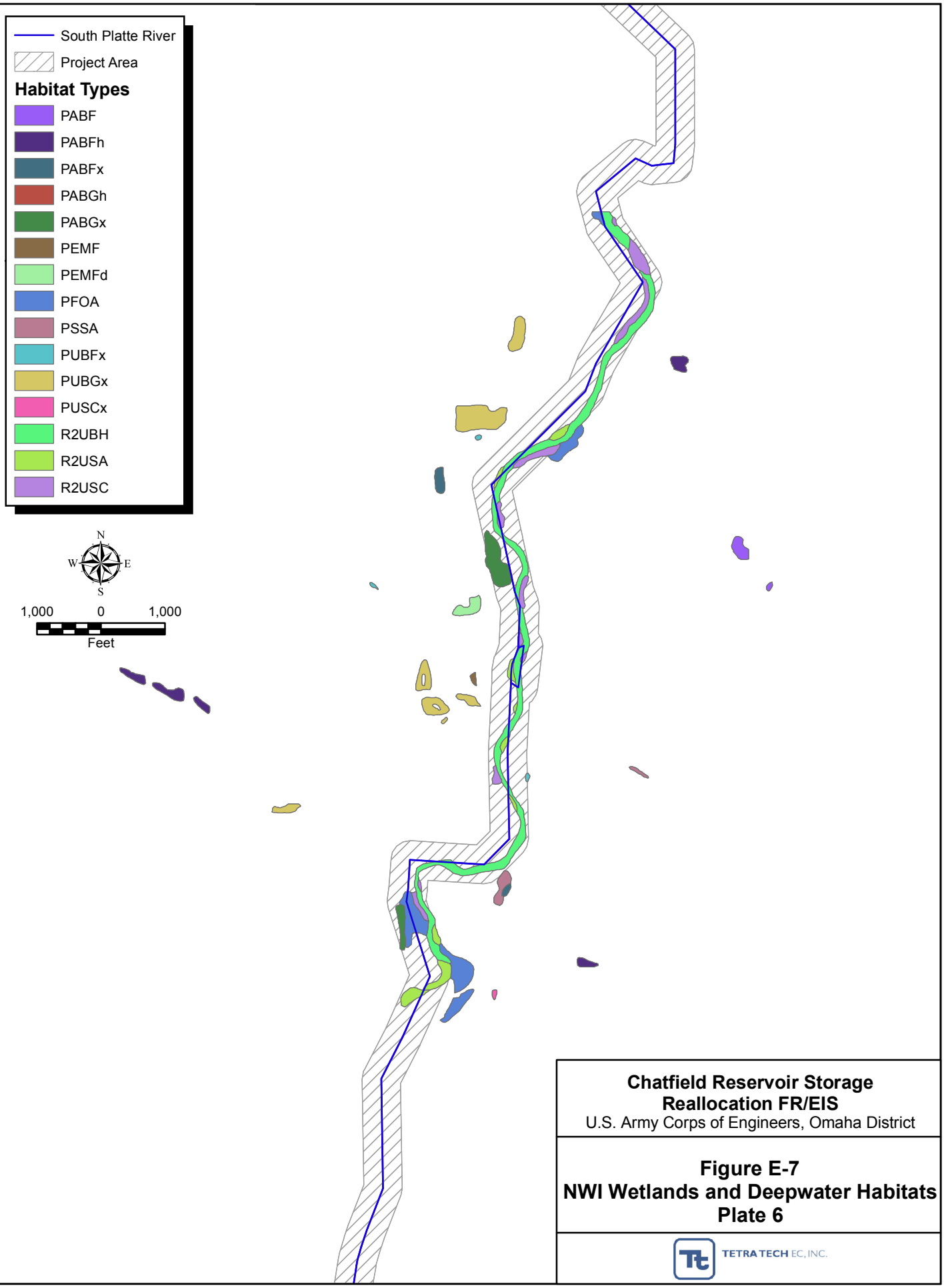

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U.S. Army Corps of Engineers, Omaha District

Figure E-7
NWI Wetlands and Deepwater Habitats
Plate 6

TETRA TECH EC, INC.

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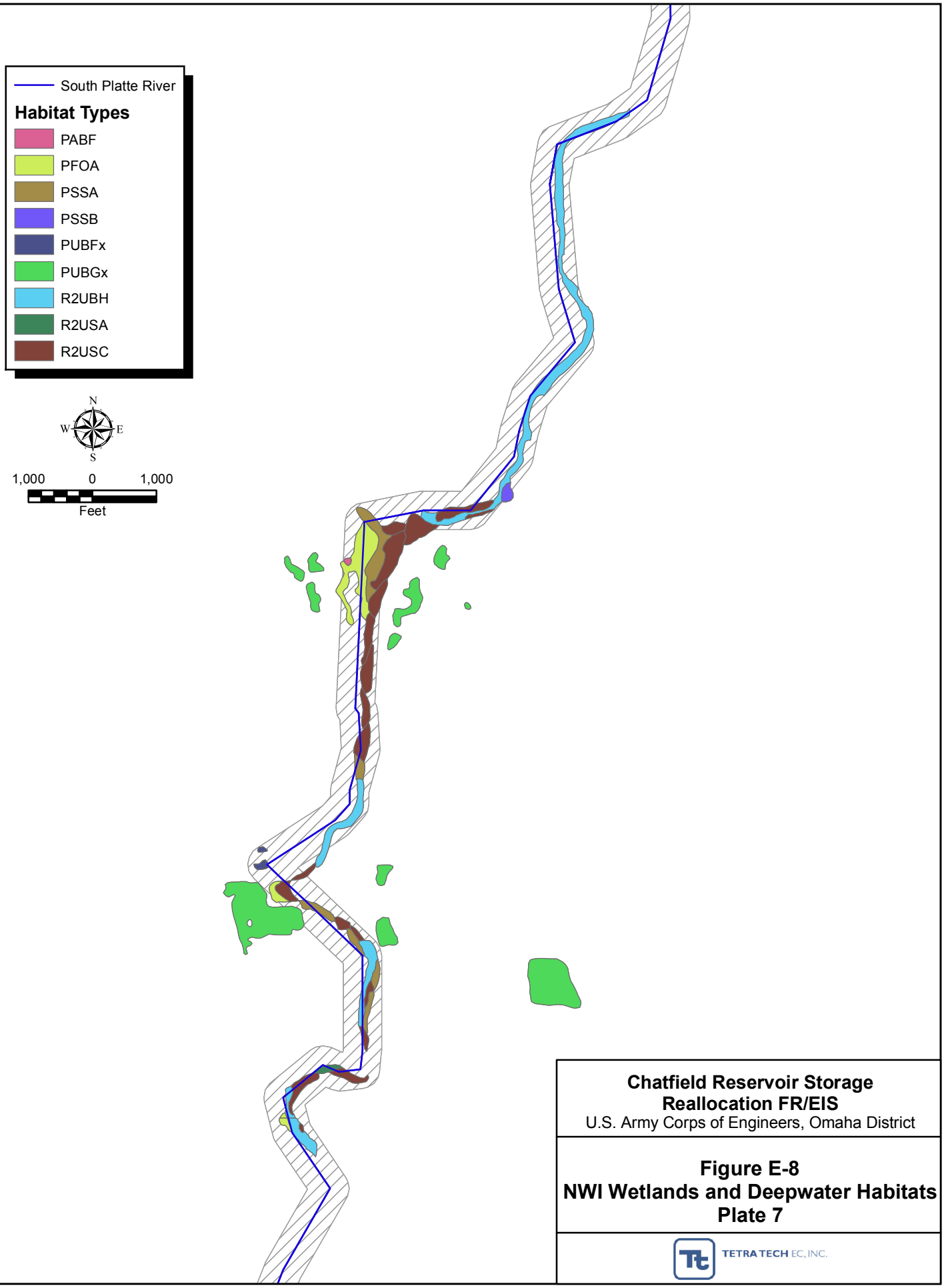

Chatfield Reservoir Storage Reallocation FR/EIS
U.S. Army Corps of Engineers, Omaha District

Figure E-8
NWI Wetlands and Deepwater Habitats
Plate 7

TETRA TECH EC, INC.

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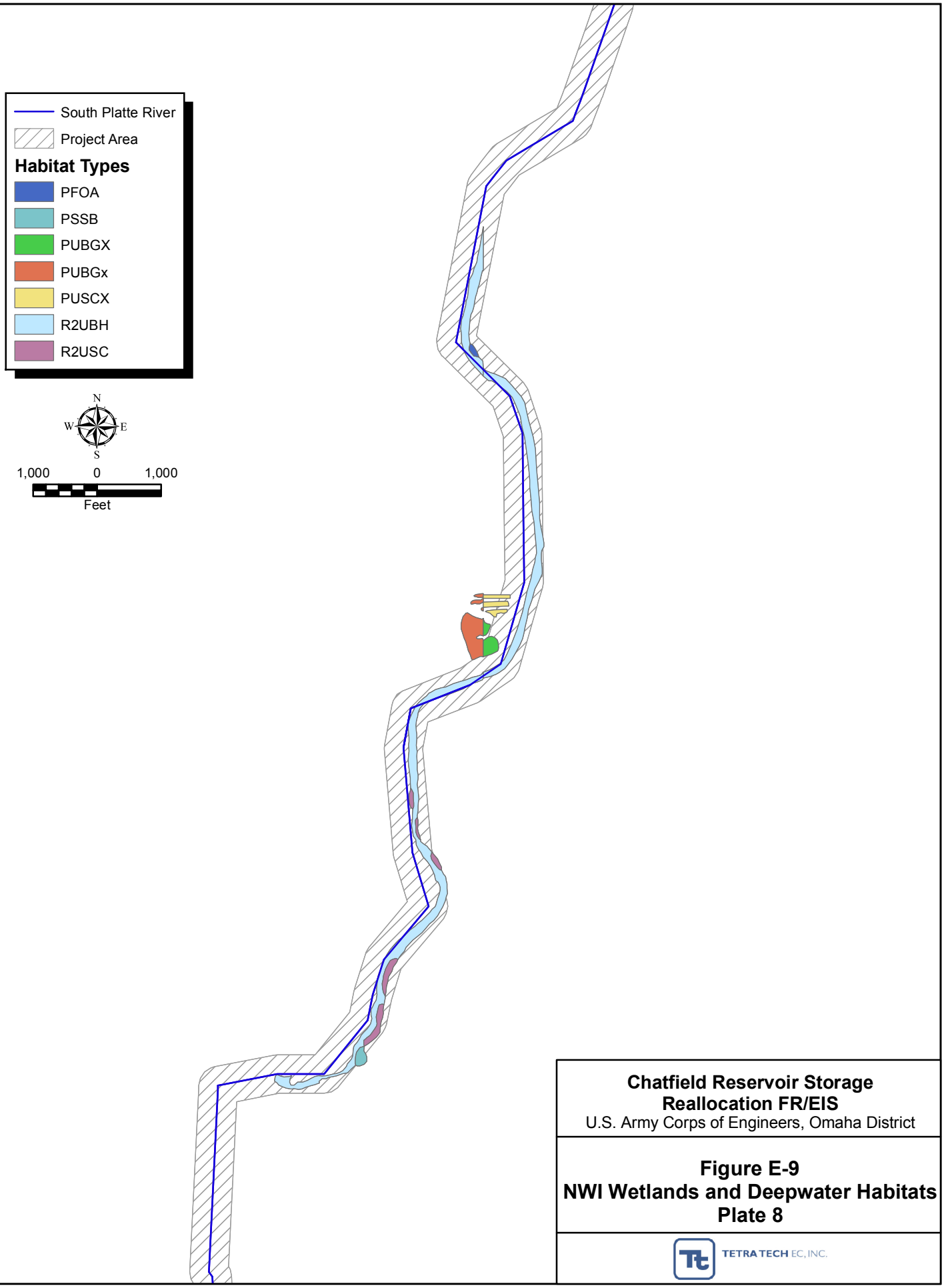

Chatfield Reservoir Storage Reallocation FR/EIS
U.S. Army Corps of Engineers, Omaha District

Figure E-9
NWI Wetlands and Deepwater Habitats
Plate 8

TETRA TECH EC, INC.

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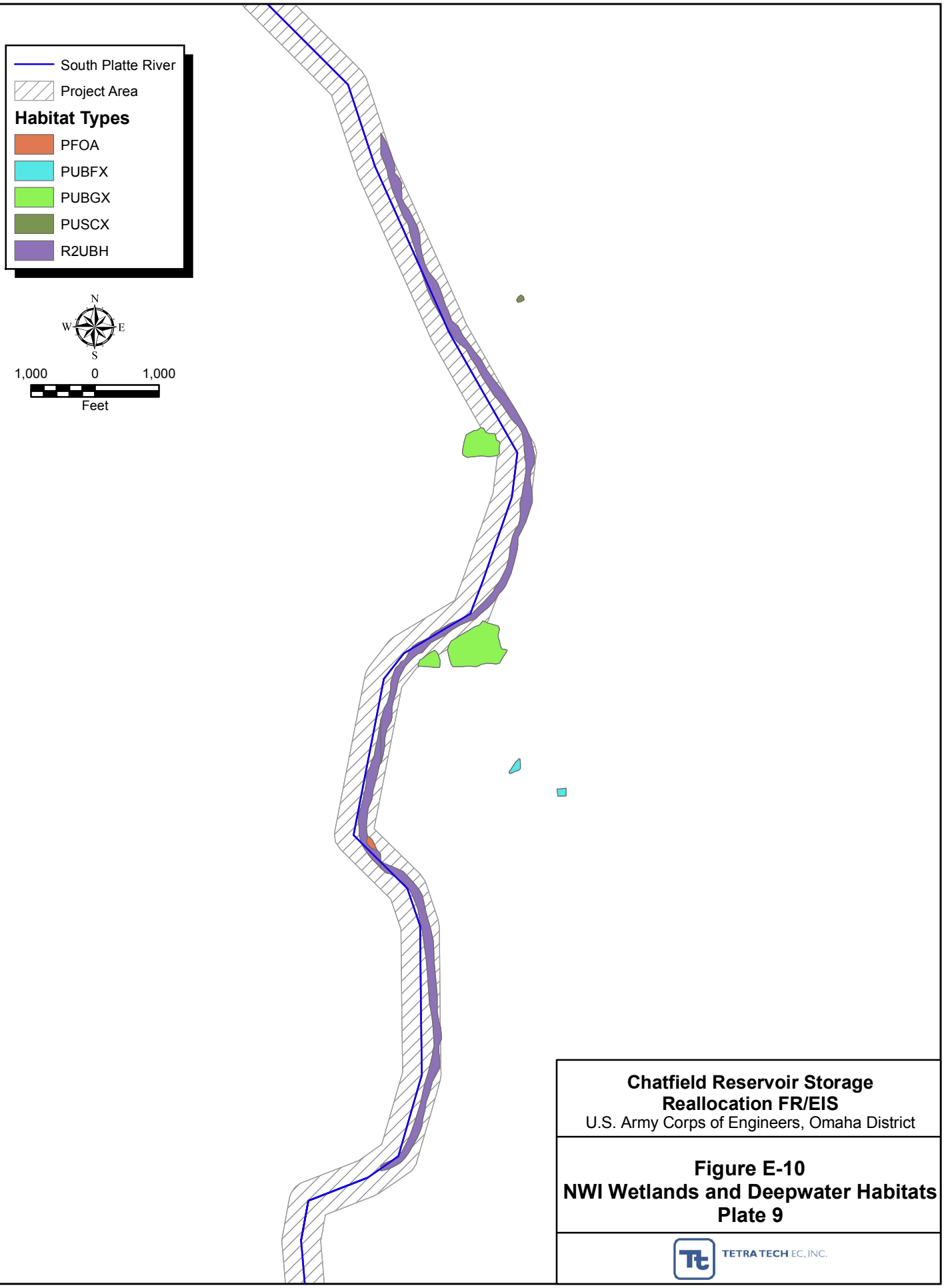

Chatfield Reservoir Storage Reallocation FR/EIS
U.S. Army Corps of Engineers, Omaha District

Figure E-10
NWI Wetlands and Deepwater Habitats
Plate 9

TETRA TECH EC, INC.

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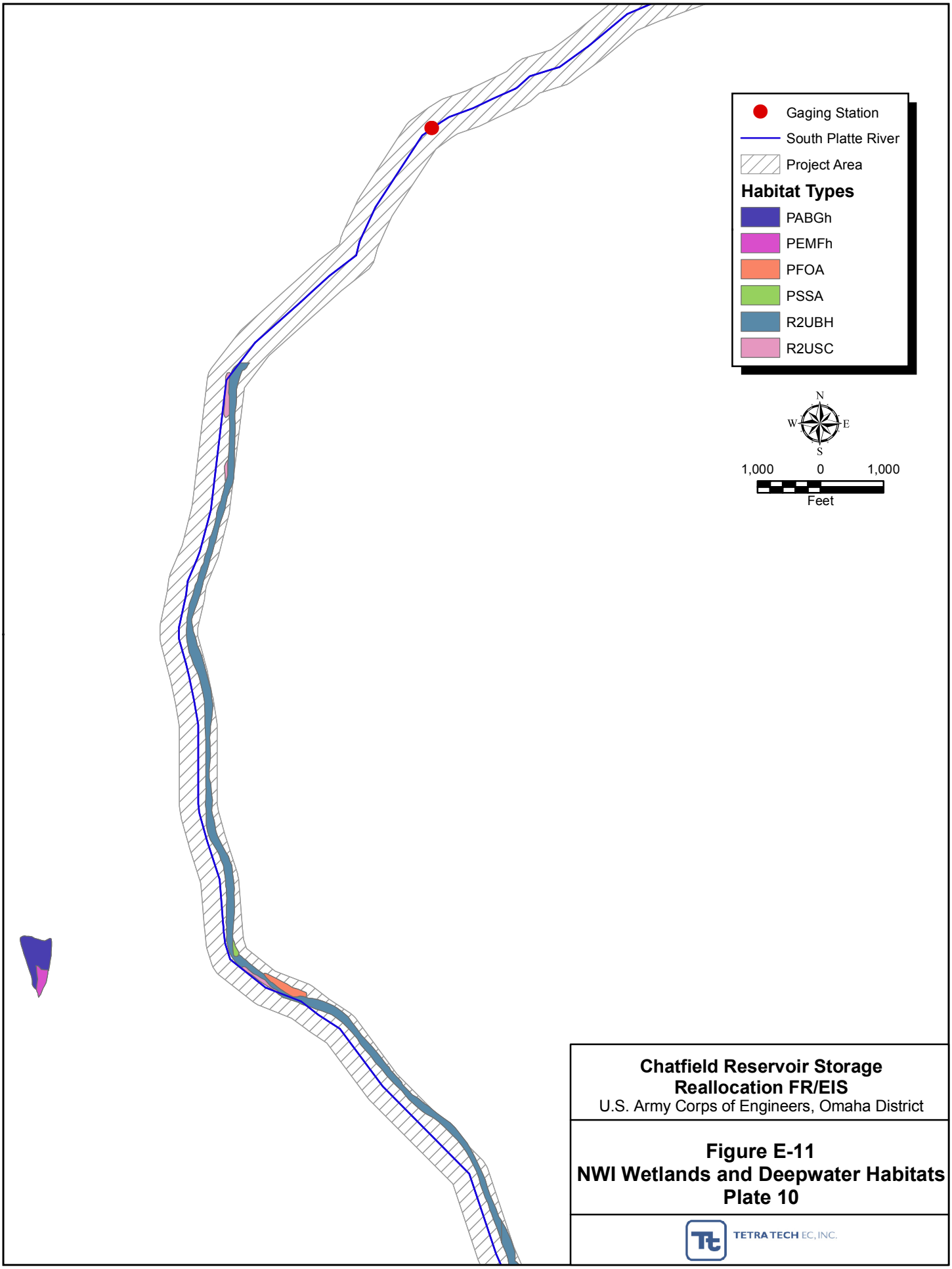

Chatfield Reservoir Storage Reallocation FR/EIS
U.S. Army Corps of Engineers, Omaha District

Figure E-11
NWI Wetlands and Deepwater Habitats
Plate 10

TETRA TECH EC, INC.

03/10/2006 J:\Chatfield_USACE\GIS\Figures\FigureA-11.mxd TtEC-Lakewood kdc

Appendix F
Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [(a)]	
Common Name	**Scientific Name**
Mammals	
Small Mammals	
Virginia opossum	*Didelphis virginianus*
Merriam's shrew	*Sorex merriami*
Least shrew	*Cryptotis parva*
Western small-footed myotis	*Myotis ciliolabrum*
Long-eared myotis	*Myotis evotis*
Little brown myotis	*Myotis lucifugus*
Red bat	*Lasiurus borealis*
Hoary bat	*Lasiurus cinereus*
Silver-haired bat	*Lasionycteris noctivagans*
Big brown bat	*Eptesicus fuscus*
Desert cottontail	*Sylvilagus audubonii*
Eastern cottontail	*Sylvilagus floridanus*
Black-tailed jackrabbit	*Lepus californicus*
White-tailed jackrabbit	*Lepus townsendii*
Spotted ground squirrel	*Spermophilus spilosoma*
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*
Rock squirrel	*Spermophilus variegatus*
Black-tailed prairie dog	*Cynomys ludocicianus*
Fox squirrel	*Sciurus niger*
Northern pocket gopher	*Thomomys talpoides*
Plains pocket gopher	*Geomys bursarius*
Olive-backed pocket mouse	*Perognathus fasciatus*
Plains pocket mouse	*Perognathus flavescens*
House mouse	*Mus musculus*
Silky pocket mouse	*Perognathus flavus*
Hispid pocket mouse	*Chaetodipus hispidus*
Ord's kangaroo rat	*Dipodomys ordii*
Western harvest mouse	*Reithrodontomys megalotis*
Brush mouse	*Peromyscus boylii*
Deer mouse	*Peromyscus maniculatus*
Northern grasshopper mouse	*Onychomys leucogaster*
Mexican woodrat	*Neotoma mexicana*
Prairie vole	*Microtus ochrogaster*
Meadow vole	*Microtus pennsylvanicus*
Muskrat	*Ondatra zibethicus*
Meadow jumping mouse	*Zapus hudsonius*
Long-tailed weasel	*Mustela frenata*
Medium-Sized Mammals	
Coyote	*Canis lupus*
Red fox	*Vulpes vulpes*
Mountain lion	*Felis concolor*
Bobcat	*Lynx rufus*

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [(a)]	
Common Name	**Scientific Name**
American badger	*Taxidea taxus*
Beaver	*Castor canadensis*
Porcupine	*Erethizon dorsatum*
Raccoon	*Procyon lotor*
Striped skunk	*Mephitis mephitis*
Large Mammals	
Black bear	*Ursus americanus*
Mule deer	*Odocoileus hemionus*
White-tailed deer	*Odocoileus virginianus*
Elk	*Cervus elaphus*
Birds (b,c)	
ANSERIFORMES	
Canada goose	*Branta canadensis*
Tundra swan	*Cygnus columbianus*
Wood duck	*Aix sponsa*
Gadwall	*Anas strepera*
American wigeon	*Anas americana*
Mallard	*Anas platyrhynchos*
Blue-winged teal	*Anas discors*
Cinnamon teal	*Anas cyanoptera*
Northern shoveler	*Anas clypeata*
Northern pintail	*Anas acuta*
Green-winged teal	*Anas crecca*
Canvasback	*Aythya valisineria*
Redhead	*Aythya americana*
Ring-necked duck	*Aythya collaris*
Lesser scaup	*Aythya affinis*
Bufflehead	*Bucephala albeola*
Common goldeneye	*Bucephala clangula*
Hooded merganser	*Lophodytes cucullatus*
Common merganser	*Mergus merganser*
Red-breasted merganser	*Mergus serrator*
Ruddy duck	*Oxyura jamacensis*
GALLIFORMES	
Ring-necked pheasant	*Phasianus colchicus*
GAVIIFORMES	
Pacific loon	*Gavia pacifica*
Common loon	*Gavia immer*
PODICIPEDIFORMES	
Pied-billed grebe	*Podilymbus podiceps*
Horned grebe	*Podiceps auritus*
Eared grebe	*Podiceps nigricollis*

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [(a)]	
Common Name	**Scientific Name**
Western grebe	*Aechmophorus occidentalis*
PELECANIFORMES	
American white pelican	*Pelecanus erythrorhynchos*
Double-crested cormorant	*Phalacrocorax auritus*
CICONIIFORMES	
Great blue heron	*Ardea herodias*
Snowy egret	*Egretta thula*
Cattle egret	*Bubulcus ibis*
Green heron	*Butorides virescens*
Black-crowned night-heron	*Nycticorax nycticorax*
White-faced ibis	*Plegadis chihi*
FALCONIFORMES	
Turkey vulture	*Cathartes aura*
Osprey	*Pandion haliaetus*
Bald eagle	*Haliaeetus leucocephalus*
Northern harrier	*Circus cyaneus*
Sharp-shinned hawk	*Accipiter striatus*
Cooper's hawk	*Accipiter cooperii*
Northern goshawk	*Accipiter gentilis*
Broad-winged hawk	*Buteo platypterus*
Swainson's hawk	*Buteo swainsoni*
Red-tailed hawk	*Buteo jamaicensis*
Ferruginous hawk	*Buteo regalis*
Rough-legged hawk	*Buteo lagopus*
Golden eagle	*Aquila chrysaetos*
American kestrel	*Falco sparverius*
Merlin	*Falco columbarius*
Peregrine falcon	*Falco peregrinus*
Prairie falcon	*Falco mexicanus*
GRUIFORMES	
Virginia rail	*Rallus limicola*
Sora	*Porzana carolina*
American coot	*Fulica americana*
CHARADRIIFORMES	
Semi-palmated plover	*Charadrius semipalmatus*
Killdeer	*Charadrius vociferus*
American avocet	*Recurvirostra americana*
Spotted sandpiper	*Actitis macularia*
Solitary sandpiper	*Tringa solitaria*
Greater yellowlegs	*Tringa melanoleuca*
Willet	*Tringa semipalmata*
Lesser yellowlegs	*Tringa flavipes*
Marbled godwit	*Limosa fedoa*
Sanderling	*Calidris alba*

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [(a)]	
Common Name	**Scientific Name**
Semi-palmated sandpiper	*Calidris pusilla*
Western sandpiper	*Calidris mauri*
Least sandpiper	*Calidris minutilla*
Baird's sandpiper	*Calidris bairdii*
Pectoral sandpiper	*Calidris melanotos*
Long-billed dowitcher	*Limnodromus scolopaceus*
Common snipe	*Gallinago gallinago*
Wilson's phalarope	*Phalaropus tricolor*
Franklin's gull	*Larus pipixcan*
Bonaparte's gull	*Larus philadelphia*
Ring-billed gull	*Larus delawarensis*
California gull	*Larus californicus*
Herring gull	*Larus argentatus*
Thayer's gull	*Larus thayeri*
Black tern	*Chlidonias niger*
Common tern	*Sterna hirundo*
Forster's tern	*Sterna forsteri*
COLUMBIFORMES	
Rock pigeon	*Columba livia*
Mourning dove	*Zenaida macroura*
CUCULIFORMES	
Yellow-billed cuckoo	*Coccyzus americanus*
STRIGIFORMES	
Eastern screech-owl	*Megascops asio*
Great horned owl	*Bubo virginianus*
Long-eared owl	*Asio otus*
CAPRIMULGIFORMES	
Common nighthawk	*Chordeiles minor*
APODIFORMES	
White-throated swift	*Aeronautes saxatalis*
Broad-tailed hummingbird	*Selasphorus platycercus*
CORACIIFORMES	
Belted kingfisher	*Ceryle alcyon*
PICIFORMES	
Lewis' woodpecker	*Melanerpes lewis*
Red-headed woodpecker	*Melanerpes erythrocephalus*
Downy woodpecker	*Picoides pubescens*
Hairy woodpecker	*Picoides villosus*
Northern flicker	*Colaptes auratus*
PASSERIFORMES	
Olive-sided flycatcher	*Contopus cooperi*
Western wood-peewee	*Contopus sordidulus*
Willow flycatcher	*Empidonax traillii*

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [(a)]	
Common Name	**Scientific Name**
Least flycatcher	*Empidonax minimus*
Hammond's flycatcher	*Empidonax hammondii*
Dusky flycatcher	*Empidonax oberholseri*
Cordilleran flycatcher	*Empidonax occidentalis*
Eastern phoebe	*Sayornis phoebe*
Say's phoebe	*Sayornis saya*
Western kingbird	*Tyrannus verticalis*
Eastern kingbird	*Tyrannus tyrannus*
Loggerhead shrike	*Lanius ludovicianus*
Northern shrike	*Lanius excubitor*
Plumbeous vireo	*Vireo plumbeus*
Warbling vireo	*Vireo gilvus*
Red-eyed vireo	*Vireo olivaceus*
Steller's jay	*Cyanocitta stelleri*
Blue jay	*Cyanocitta cristata*
Western scrub-jay	*Aphelocoma californica*
Black-billed magpie	*Pica hudsonica*
American crow	*Corvus brachyrhynchos*
Common raven	*Corvus corax*
Horned lark	*Eremophila alpestris*
Tree swallow	*Tachycineta bicolor*
Violet-green swallow	*Tachycineta thalassina*
Northern rough-winged swallow	*Stelgidopteryx serripennis*
Bank swallow	*Ripara riparia*
Cliff swallow	*Petrochelidon pyrrhonota*
Barn swallow	*Hirundo rustica*
Black-capped chickadee	*Poecile atricapillus*
Mountain chickadee	*Poecile gambeli*
Red-breasted nuthatch	*Sitta canadensis*
White-breasted nuthatch	*Sitta carolinensis*
Brown creeper	*Certhia ameriicana*
Rock wren	*Salpinctes obsoletus*
Canyon wren	*Catherpes mexicanus*
House wren	*Troglodytes aedon*
Winter wren	*Troglodytes troglodytes*
Marsh wren	*Cistothorus palustris*
American dipper	*Cinclus mexicanus*
Ruby-crowned kinglet	*Regulus calendula*
Blue-gray gnatcatcher	*Polioptila caerulea*
Western bluebird	*Sialia mexicana*
Mountain bluebird	*Sialia currucoides*
Townsend's solitaire	*Myadestes townsendi*
Swainson's thrush	*Catharus ustulatus*
Hermit thrush	*Catharus guttatus*

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [(a)]	
Common Name	**Scientific Name**
American robin	*Turdus migratorius*
Gray catbird	*Dumetella carolinensis*
Northern mockingbird	*Mimus polyglottos*
Sage thrasher	*Oreoscoptes montanus*
Brown thrasher	*Toxostoma rufum*
European starling	*Sturnus vulgaris*
American pipit	*Anthus rubescens*
Bohemian waxwing	*Bombycilla garrulus*
Cedar waxwing	*Bombycilla cedrorum*
Orange-crowned warbler	*Vermivora celata*
Virginia's warbler	*Vermivora virginiae*
Northern parula	*Parula americana*
Yellow warbler	*Dendroica petechia*
Yellow-rumped warbler	*Dendroica coronata*
Townsend's warbler	*Dendroica townsendi*
American redstart	*Setophaga ruticilla*
Northern waterthrush	*Seiurus noveboracensis*
MacGillivray's warbler	*Oporornis tolmiei*
Common yellowthroat	*Geothlypis trichas*
Wilson's warbler	*Wilsonia pusilla*
Yellow-breasted chat	*Icteria virens*
Western tanager	*Piranga ludoviciana*
Green-tailed towhee	*Pipilo chlorurus*
Spotted towhee	*Pipilo maculatus*
American tree sparrow	*Spizella arborea*
Chipping sparrow	*Spizella passerina*
Clay-colored sparrow	*Spizella pallida*
Brewer's sparrow	*Spizella breweri*
Vesper sparrow	*Pooecetes gramineus*
Lark sparrow	*Chondestes grammacus*
Lark bunting	*Calamospiza melanocorys*
Savannah sparrow	*Passerculus sandwichensis*
Grasshopper sparrow	*Ammodramus savannarum*
Song sparrow	*Melospiza melodia*
Lincoln's sparrow	*Melospiza lincolnii*
Swamp sparrow	*Melospiza georgiana*
White-throated sparrow	*Zonotrichia albicollis*
Harris's sparrow	*Zonotrichia querula*
White-crowned sparrow	*Zonotrichia leucophrys*
Dark-eyed junco	*Junco hyemalis*
Lapland longspur	*Calcarius lapponicus*
Rose-breasted grosbeak	*Pheucticus ludovicianus*
Black-headed grosbeak	*Pheucticus melanocephalus*
Blue grosbeak	*Passerina caerulea*

Species of Mammals, Birds, Reptiles, and Amphibians Known to Occur in the Project Area [a]	
Common Name	**Scientific Name**
Lazuli bunting	*Passerina amoena*
Indigo bunting	*Passerina cyanea*
Red-winged blackbird	*Agelaius phoeniceus*
Western meadowlark	*Sturnella neglecta*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*
Brewer's blackbird	*Euphagus cyanocephalus*
Common grackle	*Quisalus quiscula*
Brown-headed cowbird	*Molothrus ater*
Bullock's oriole	*Icterus bullockii*
House finch	*Carpodacus mexicanus*
Pine siskin	*Carduelis pinus*
Lesser goldfinch	*Carduelis psaltria*
American goldfinch	*Carduelis tristis*
Evening grosbeak	*Coccothraustes vespertinus*
House sparrow	*Passer domesticus*
Reptiles	
Snapping turtle	*Chelydra serpentina*
Painted turtle	*Chrysemys picta*
Western fence lizard	*Sceloporus occidentalis*
Short-horned lizard	*Phrynosoma hernandesi*
Prairie lizard	*Sceloporus undulatus*
Six-lined race runner	*Cnemidophorus sexlineatus*
Racer	*Coluber constrictor*
Western hognose snake	*Heterodon nasicus*
Northern water snake	*Nerodia sipedon*
Bullsnake	*Pituophis catenifer*
Plains garter snake	*Thamnophis radix*
Western rattlesnake	*Crotalus viridis*
Amphibians	
Tiger salamander	*Ambystoma tigrinum*
Plains spadefoot	*Spea bombifrons*
Great Plains toad	*Bufo cognatus*
Woodhouse's toad	*Bufo woodhousii*
Western chorus frog	*Pseudacris triseriata*
Bullfrog	*Rana catesbeiana*

[a] Developed from information in Fitzgerald et al. 1994, Hammerson 1999, and South Suburban Park and Recreation District, no date, and information gathered during the July 13, 2000 site visit

[b] The order in which the birds are listed and the common and scientific names are based on the American Ornithologists' Union current Checklist of North American Birds (AOU 2007). The subheadings under Birds (e.g., "Anseriformes") are the taxonomic orders based on AOU (2007).

[c] List of birds at Chatfield is based on Colorado State Parks (1998). Species characterized in Colorado State Parks (1998) as "Infrequently Seen" are not included in the table. See Chapter 3 for additional information on bird species at Chatfield.

Appendix G
Butterfly Species Identified at Denver Botanic Gardens at Chatfield, 1992-2001

Butterfly Species Identified at Denver Botanic Gardens at Chatfield, 1992-2001[1]

Common Name	Scientific Name
Papilionidae[2]	
Black Swallowtail	*Papilio polyxenes*
Giant Swallowtail	*Papilio cresphontes*
Western Tiger Swallowtail	*Papilio rutulus*
Two-tailed Swallowtail	*Papilio multicaudatus*
Pale Swallowtail	*Papilio eurymedon*
Pieridae	
Checkered White	*Pontia protodice*
Western White	*Pontia occidentalis*
Cabbage White	*Pieris rapae*
Clouded Sulphur	*Colias philodice*
Orange (Alfalfa) Sulphur	*Colias eurytheme*
Queen Alexandra's Sulphur	*Colias alexandra*
Mexican Yellow	*Eurema mexicana*
Lycaenidae	
Gray Copper	*Lycaena dione*
Bronze Copper	*Lycaena hyllus*
Purplish Copper	*Lycaena helloides*
Striped Hairstreak	*Satyrium liparops*
Gray Hairstreak	*Strymon melinus*
Marine Blue	*Leptodes marina*
Reakirt's Blue	*Hemiargus isola*
Silvery Blue	*Glaucopsyche lygdamus*
Melissa (Orange-bordered) Blue	*Lycaeides melissa*
Libytheidae	
American Snout	*Libytheana carinenta*
Nymphalidae	
Variegated Fritillary	*Euptoieta Claudia*
Aphrodite Fritillary	*Speyeria Aphrodite*
Field Crescent	*Phyciodes campestris*
Satyr Comma	*Polygonia satyrus*
Mourning Cloak	*Nymphalis antiopa*
Milbert's Tortoiseshell	*Nymphalis milberti*
Painted Lady	*Vanessa cardui*
Red Admiral	*Vanessa atalanta*
Weidemeyer's Admiral	*Limenitis weidemeyerii*
Hackberry Emperor	*Asterocampa celtis*
Satyridae	
Common (Ochre) Ringlet	*Coenonympha tullia*
Common Wood-Nymph	*Cercyonis pegala*
Danaidae	
Monarch	*Danaus plexippus*
Queen	*Danaus gilippus*

Common Name	Scientific Name
Hesperiidae	
Silver-Spotted Skipper	*Epargyreus clarus*
Afranius Duskywing	*Erynnis afranius*
Small Checkered Skipper	*Pyrgus scriptura*
Common Checkered Skipper	*Pyrgus communis*
Common Sootywing	*Pholisora Catullus*
Russet Skipperling	*Piruna pirus*
Delaware Skipper	*Atrytone logan*
Taxiles Skipper	*Poanes taxiles*

[1]Survey results are from Wiseman 2006; Scientific and Common names are as cited in Wiseman 2006.
[2]Subheadings are butterfly Families.

Appendix H
USACE Hydrology Report:
Chatfield Dam and Reservoir

US Army Corps
of Engineers ®
Omaha District

CHATFIELD DAM AND RESERVOIR
DENVER, COLORADO

FINAL REPORT

Feasibility Study
December 2006 (updated December 2008)

CHATFIELD DAM AND RESERVOIR REALLOCATION STUDY

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INTRODUCTION

Study Purpose

Due to the growing demands for municipal water supplies in the Denver Metro area, in 1997, the Colorado Water Conservation Board requested the U.S. Army Corps of Engineers (Corps) undertake a study of Chatfield Reservoir to reallocate a portion of the flood control storage for municipal water supply. The Tri-Lakes feasibility study was initiated in 1998 to evaluate the impacts of reallocating up to 20,600 acre-feet of flood control storage for water supply purposes. The purpose of this feasibility study is to investigate the potential impacts the reallocation would have on flood control regulation, recreation, and fish and wildlife both, upstream and downstream of the reservoir.

Study Scope

A scope of work was developed for the hydrologic analysis of the reallocation of storage from flood control to multi-purpose use for Chatfield Dam. Numerous objectives were established which examined and addressed, 1) setting up and calibrating a model to simulate the Corps' three flood control reservoirs located in the Denver area for a historical period of record, 2) Adjust historic streamflows to account for current urbanization through the study reach, and 3) develop flow and elevation duration and probability relationships for both, the Corps reservoirs and for the South Platte River downstream of the reservoirs for with and without project conditions.

Study Area

The study area encompasses the Denver, Colorado and vicinity, which is located in the north central portion of the state. The area includes the South Platte River from Chatfield Reservoir downstream to Julesburg, Colorado and includes Chatfield, Bear Creek, and Cherry Creek Reservoirs. A map of the area is shown on Figure 1.

Basin Description

The South Platte River basin originates along the eastern slope of the Continental Divide and flows in a southeasterly direction into Eleven Mile Canyon Reservoir. From there, the river changes direction, flows northeast to Cheesman Reservoir and then on to Chatfield Reservoir. The flow of the South Platte River at the Chatfield site is affected by transmountain diversions (which import water to the basin from the western slopes of the Rocky Mountains), storage reservoirs, power developments, diversions for irrigation and municipal use, and return flow from irrigated areas.

The drainage area above Chatfield Reservoir encompasses an area of 3,018 square miles. The topography of the basin varies greatly; ranging from mountainous

SOUTH PLATTE RIVER BASIN

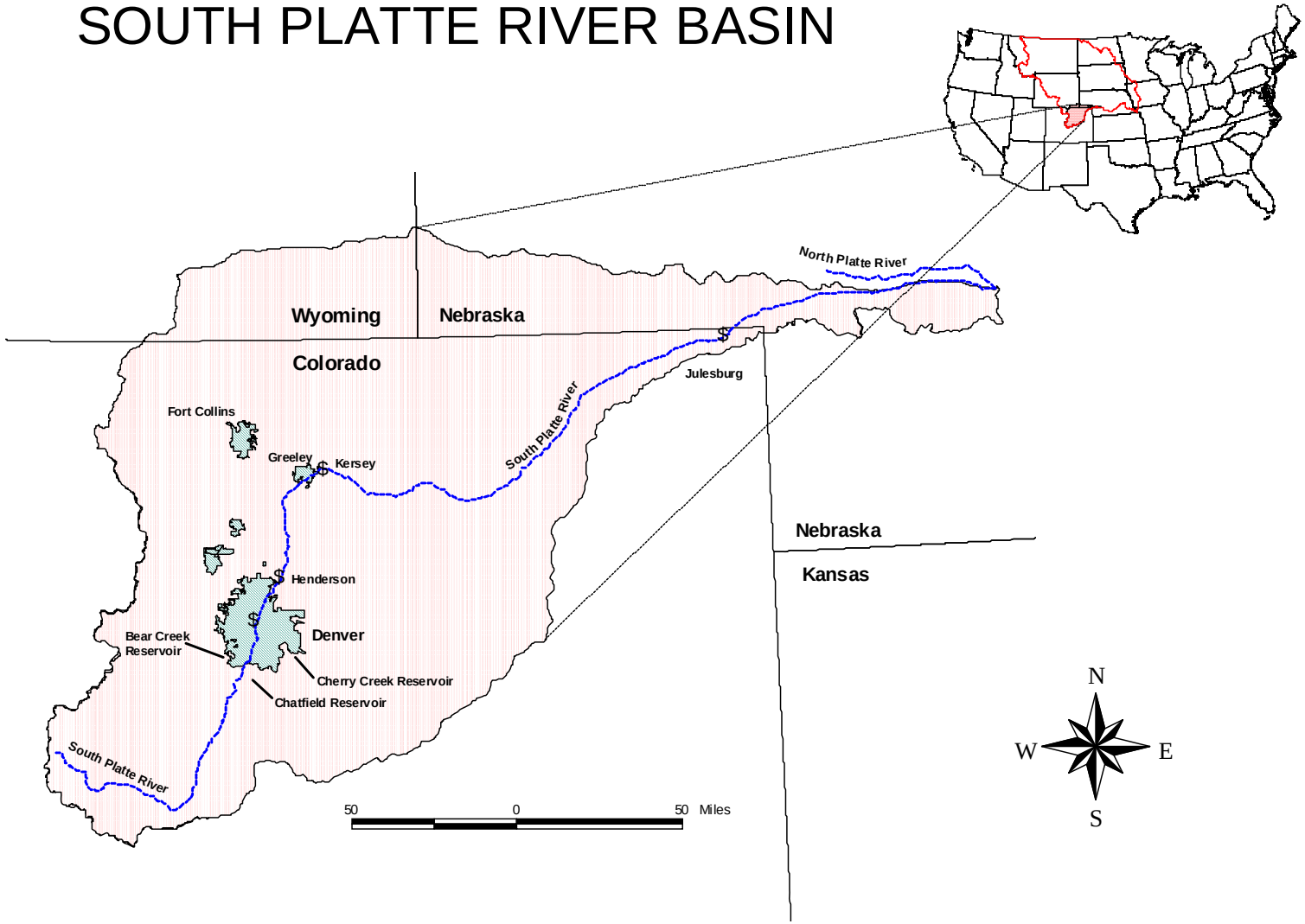


Figure 1 – Location Map – South Platte River Basin

terrain with peak elevations exceeding 14,000 feet above mean sea level (ft msl) on the Continental Divide to rolling foothills and high plains with elevations near 5,400 ft msl at Chatfield Dam.

Downstream of Chatfield Dam, the South Platte River continues to travel to the northeast to where the river confluences with the North Platte River near North Platte, Nebraska to form the Platte River. The channel capacity varies between Denver and Henderson. The river channel below Chatfield Dam and above the Bear Creek confluence can safely pass 5,000 cubic feet per second (cfs). Through Denver, the channel capacity is approximately 10,000 cfs. However, channel capacity further downstream near Henderson, Colorado varies between 3,000 and 5,000 cfs.

Annual precipitation ranges from 30 inches near the Continental Divide to less than 15 inches on the plains. Most of the precipitation in the mountains occurs as snow, which typically falls between October and March. On the plains, precipitation falls mainly between April and September. A major portion of the annual inflow into Chatfield Reservoir results from the mountain snowmelt. Flooding in the Denver area is usually the result of intense thunderstorm rainfall or from snowmelt augmented by rainfall.

Three major flood control reservoirs are located on the South Platte River or its tributaries; Chatfield Dam, Bear Creek Dam, and Cherry Creek Dam. These three reservoirs control flooding through the Denver area along the South Platte River. All three projects are federally owned facilities, with project operation and maintenance functions the responsibility of the Tri-Lakes Project Manager under the direction of Operations Division, Omaha District, Northwestern Division, U.S. Army Corps of Engineers. They operate for the benefit of flood control, recreation, and fish and wildlife purposes. A summary of reservoir data for all three reservoirs is listed in Table 1.

Chatfield Dam and Reservoir is located on the South Platte River immediately downstream of the confluence of the South Platte River and Plum Creek, about 8 miles upstream of Denver, Colorado. The Chatfield Project was authorized by the Flood Control Act of 1950. Construction on the project was initiated in 1967, closure of the dam was made in late summer 1973, the outlet works completed in 1974, and the spillway construction was completed in April 1975. Chatfield Dam is a multi-purpose project consisting of an earthfill embankment, emergency spillway, outlet works and a multi-purpose reservoir. At the top of conservation pool (5432 ft msl) Chatfield Reservoir extends 2.5 miles upstream, has a surface area of 1,423 acres, less than 10 miles of shoreline and a maximum depth of 55 feet. The Denver Water Board, through the Colorado Water Conservation Board, owns 11,000 acre-feet of storage in Chatfield Reservoir.

Cherry Creek Dam and Reservoir is located on Cherry Creek just southeast of the City of Denver, Colorado, in Arapahoe County, 11.4 miles above the confluence with the South Platte River. The Cherry Creek Project was authorized by the Flood Control Act of 1941 and 1944. Construction on the project was initiated in July 1946,

closure of the dam was made in October 1948, the outlet works completed in 1949 and the embankment and spillway construction were completed in January 1950. Cherry Creek Dam is a multi-purpose project consisting of an earthfill embankment, emergency spillway, outlet works and a multi-purpose reservoir. At the top of conservation pool (5550 ft msl) Cherry Creek Reservoir extends 1.5 miles upstream, has a surface area of 844 acres, less than 7 miles of shoreline and a maximum depth of 46 feet. Currently there is no water supply storage allocation in Cherry Creek Reservoir.

Corps of Engineers design guidance for dams located above populated areas states they should safely pass a Probable Maximum Flood (PMF) without overtopping the embankment. The most recent precipitation estimates prepared by the National Weather Service for this area indicate that Cherry Creek Reservoir could safely pass no more than 75% of the PMF under existing development with adequate freeboard. A dam safety evaluation study to determine optimal solutions to the hydrologic inadequacy of Cherry Creek Reservoir is underway, with current studies focused on development of the Probable Maximum Precipitation (PMP). A new development relative to Cherry Creek Dam is that all Corps dams are being screened and assigned a safety classification rating. This Dam Safety Action Classification (DSAC) system classifies dams into five classes with class I having the highest priority for attention and class V the lowest priority. Using the new criteria, Cherry Creek Dam has received a DSAC II rating because of the amount of development below the dam and the PMF studies that have identified a potential for an extreme precipitation event that could fill the reservoir and possibly overtop the dam. Part of the screening process for Corps dams with a DSAC rating of I, II or III is to identify interim measures to reduce safety risks while long-term solutions are being pursued. These measures could be structural or non-structural. Some of the measures being implemented for Cherry Creek Dam are an improved flood warning system, updating response procedures with emergency managers, evaluating the capacities of the downstream channel and emergency spillway, as well as evaluating the vulnerability to seepage and earthquakes. The reservoir data on Cherry Creek Dam in Table 1 reflects original design conditions and will change with the completion of the Dam Safety Assurance Study.

Table 1
Summary of Reservoir Data

Zone	Top of Zone Elevation (ft msl)	Surface Area (acres)	Gross Storage (acre-feet)	Incremental Storage (acre-feet)
Chatfield Dam				
Top of Dam	5527.0	-------	-------	-------
Maximum Surcharge - Spillway Design Flood	5521.6	5,990	350,700	116,500
Flood Control Pool - Spillway Crest	5500.0	4,780	234,200	206,800
Multipurpose Pool	5432.0	1,430	27,400	7,800

Table 1
Summary of Reservoir Data

Zone	Top of Zone Elevation (ft msl)	Surface Area (acres)	Gross Storage (acre-feet)	Incremental Storage (acre-feet)
Sediment	5426.0	1,180	19,600	19,600
Inactive	5385.0	12	23	23
Bear Creek Dam				
Top of Dam	5689.5	-------	-------	-------
Maximum Surcharge - Spillway Design Flood	5684.5	1,220	78,000	47,300
Flood Control Pool	5635.5	715	30,700	28,700
Multipurpose Pool	5558.0	107	1,970	1,905
Inactive	5528.0	16	65	65
Cherry Creek Dam				
Top of Dam	5644.5	-------	-------	-------
Maximum Surcharge - Spillway Design Flood	5636.2	4,540	226,600	134,500
Flood Control Pool - Spillway Crest	5598.0	2,640	92,100	79,300
Multipurpose Pool	5550.0	850	12,800	12,800

Bear Creek Dam and Reservoir is located west of Denver on Bear Creek, approximately 8.0 miles upstream of the confluence with the South Platte River. The Bear Creek Project was authorized by the Flood Control Act of 1968. Construction on the project was initiated in October 1973, closure of the dam was made in July 1977, the outlet works completed in 1977, and the embankment and spillway construction were completed in July 1979. Bear Creek Dam is a multi-purpose project consisting of an earthfill embankment, emergency spillway, outlet works and a multi-purpose reservoir. At the top of conservation pool (5558 ft msl) Bear Creek Reservoir extends 0.5 miles upstream, has a surface area of 110 acres, and about 2.2 miles of shoreline. Currently there is no water supply storage allocation in Bear Creek Reservoir.

Reservoir Operations

The normal regulation of the Chatfield, Bear Creek and Cherry Creek Reservoirs involves the Corps of Engineers and the State of Colorado. During flooding periods, operation of the reservoirs is the responsibility of the Corps working in conjunction with state and local authorities. During non-flood periods, the Colorado State Engineers Office keeps track of water rights calls on the South Platte River and makes requests for gate operation at the three reservoirs directly to the Tri-Lakes Project Office.

For flood control operations, Chatfield Reservoir is part of a parallel reservoir system with Bear Creek and Cherry Creek Reservoirs. During flood inflow periods and/or rising pool levels Chatfield, Cherry Creek and Bear Creek Reservoirs will be independently regulated to assure safe control of each flood event. System or coordinated regulation of the three projects in parallel will be necessary only after flood flows have entered the reservoirs and during flood storage evacuation. Evacuation of flood control storage from Chatfield as an individual project will only occur when no flood storage is occupied in Bear Creek or Cherry Creek Reservoirs. When water has accumulated in the flood storage zones of the three reservoirs, an equal protective balance of available flood storage will be maintained during the pool evacuation of these projects. Current reservoir regulation criteria (rule curves) and target flows downstream on the South Platte River used for regulating flood storage evacuation are taken from the Water Control Manuals for the three reservoirs and are listed in Table 7.

DATA ACQUISITION

For this study, considerable historical and geospatial data were required to conduct the analyses. Before the analyses began, all relevant sources of data were explored. The types of data that needed to be collected for this study included streamflow data, meteorological data, and topographic data.

Hydrologic Data

Discharge information was required for hydrologic model development, calibration, and verification, and for performing statistical analyses. The hydrologic data were obtained from the USGS Water Resources Data Reports and Corps' 0168 Daily Bulletins for reservoirs. Data on the Corps and USGS streamflow gages, their locations, gage identification numbers, periods of record, and other pertinent information are shown in Table 2.

Table 2
South Platte River Basin Gaging Station Data

Stream and Location	Station ID	Gage Type	Contributing Drainage Area (sq mi)	Period of Record
South Platte River at Littleton, CO	06710000	Flow	3,069	1942-86
Cherry Creek nr Denver, CO	06713500	Flow	409	1942-current
Cherry Creek nr Melvin, CO	06712500	Flow	360	1939-84
Bear Creek at Morrison, CO	06710500	Flow	164	1919- current
Chatfield Dam Lake	COE[1]	Stage	3,018	1975- current
Bear Creek Reservoir	COE	Stage	176	1977- current
Cherry Creek Reservoir	COE	Stage	385	1957- current
South Platte River at Denver, CO	06714000	Flow	3,861	1895- current
South Platte River at Henderson, CO	06720500	Flow	4,713	1926- current

Table 2
South Platte River Basin Gaging Station Data

Stream and Location	Station ID	Gage Type	Contributing Drainage Area (sq mi)	Period of Record
South Platte River at Kersey, CO	06754000	Flow	9,598	1901- current
South Platte River at Julesburg, CO	06764000	Flow	23,193	1902- current

[1] COE – Corps of Engineers

Meteorological Data

Meteorological records were needed for modeling. Monthly precipitation and evaporation were obtained from the Corps and the National Oceanic and Atmospheric Administration (NOAA) Climatological Data for nearby gages and are listed in Table 3.

Table 3
Climatological Data Station Data

Gage and Location	NOAA Index Number	County	Gage Type	Period of Record
Cherry Creek Reservoir	COE[1]	Arapahoe	Evaporation	1959-99
Stapleton Airport	8932	Denver	Precipitation	1948-02

[1] COE – Corps of Engineers

Other Data.

Other sources of relevant data were also used for this study. Corps of Engineers reports included, Chatfield Dam Water Control Manual (COE,1971), Bear Creek Dam Water Control Manual (COE,1977), and Cherry Creek Dam Water Control Manual (COE,1971).

HYDROLOGICAL ANALYSIS

The hydrologic analysis will be used in determining the impacts to flood control, recreation, wildlife and fisheries within the reservoir, and the impacts on downstream wildlife and fisheries, and property due to a potential permanent increase in the conservation pool for Chatfield Dam. Major tasks involved for the study include: 1) Modeling of the Tri-Lakes Reservoir System over a historic period of record. 2) Developing a historic period of record of streamflow data for the modeling. 3) Adjusting the streamflows for current level of development in the basin, 4) Establishing baseline conditions for determination of impacts on potential conservation pool raises on Chatfield Reservoir and 5) Developing flow and lake elevation duration and probability relationships for various locations throughout the study area.

Streamflow Data.

Historic streamflow records were compiled and imported into the Hydrologic Engineering Center's (HEC) data storage system HEC-DSS (HEC,1995). The database included historic: daily streamflow records, reservoir inflows, reservoir outflows, and reservoir pool elevations. The period of record used for the analysis was 1942 through 2000.

Historic Reservoir Inflows.

Since actual reservoir inflows were not available for the entire analysis period, inflow data were obtained from multiple sources. Nearby USGS gaged daily streamflow data were used for the periods when reservoir inflows were not available. After completion of the reservoirs, inflow data were calculated from daily pool elevations using the Corps' 0168 Daily Bulletins. Table 4 lists the data sources used for the reservoir inflows and when they were applied to the analysis period of record. For the South Platte River downstream of the reservoirs, daily flow records were available for the Denver, Henderson, Kersey, and Julesburg gages for the entire analysis period of record 1942 through 2000.

Table 4
Streamflow Data Used in HEC-5 Model

Gage and Location	Streamgage Used	Period of Record Used
Chatfield Reservoir	South Platte River nr Littleton, CO	Jan 1, 1942 – May 31, 1975
	Chatfield Reservoir 0168's	Jun 1, 1975 – Dec 31, 2000
Bear Creek Reservoir	Bear Creek at Morrison, CO	Jan 1, 1942 – Jul 18, 1977
	Bear Creek Reservoir 0168's	Jul 19, 1977 – Dec 31, 2000
Cherry Creek Reservoir	Cherry Creek nr Melvin, CO	Jan 1, 1942 – Aug 10, 1942
	Cherry Creek nr Denver, CO	Aug 11, 1942 – May 14, 1957
	Cherry Creek Reservoir 0168's	May 15, 1957 – Dec 31, 2000

[1] Note: 0168 inflows calculated from daily pool elevations

Local Inflows

Local or incremental inflows to the South Platte River were determined by routing the historic reservoir releases from the reservoirs to downstream USGS gage locations, then subtracting out the routed flows from the USGS observed flows. For the period prior to the reservoir being in operation, the flow at the reservoir site was routed to the downstream gage and subtracted to compute the local flows. The modified puls routing method was used to route daily flows for six reaches; 1) Chatfield Dam to Bear Creek, 2) Bear Creek Dam to the confluence with the South Platte River, 3) Cherry Creek Dam to the confluence with the South Platte River, 4) South Platte River from the Denver gage to the Henderson gage, 5) South Platte River from the Henderson gage to the Kersey gage, 6) South Platte River from the Kersey gage to the Julesburg gage.

Local or incremental flows for the South Platte River were derived for 4 reaches:

1) Chatfield reservoir to the South Platte at Denver gage.
2) Denver gage to the Henderson gage
3) Henderson gage to Kersey gage
4) Kersey gage to Julesburg gage

Local flows from just downstream of Bear Creek and Cherry Creek dams to their confluence with the South Platte River were assumed to be reflected in the local flows derived for the South Platte. In addition, it was assumed that historical diversions are reflected in the local flows and would remain constant with different operations of Chatfield, Bear Creek, and Cherry Creek Reservoirs. The flows were imported into the HEC-DSS.

Inflows Adjusted to Current Level of Development.

To maintain a consistent hydrologic response to meteorological conditions, the incremental local inflows for the entire period-of-record were adjusted to the year 2000 level of development to reflect current urbanization in the basin. A trend analysis was performed which included the evaluation of historical streamflow records on the South Platte and tributaries as well as precipitation records in the Denver area. Adjustment factors derived from the trend analysis were then applied to historical daily streamflow values.

The trend analysis for historical daily inflows to the three reservoirs was examined and no corresponding increase in runoff over time was observed. Therefore, the daily flows were not altered for reservoir inflows. The local flows downstream of the reservoirs did reflect an increasing trend in flows throughout the study period, as would be expected as a reach undergoes urbanization during the study period. Figure 2 show the local flows at the Denver gage with the increased runoff over time. A trend analysis was performed on the incremental local inflows. A linear regression curve was derived using the annual runoff volumes for each of the local inflows at the USGS streamflow gage locations on the South Platte River. The

annual volumes were then adjusted to year 2000 level of development by subtracting the regression curve value for a particular year from that same year's actual runoff and then added to the regression curve value for the year 2000. The adjusted value was then divided by the historic value to derive a ratio to apply to each of the daily values for that year. A table listing the historic values, adjusted values and the ratio applied to each year for the local inflows downstream on the South Platte River are located in Appendix H-A.

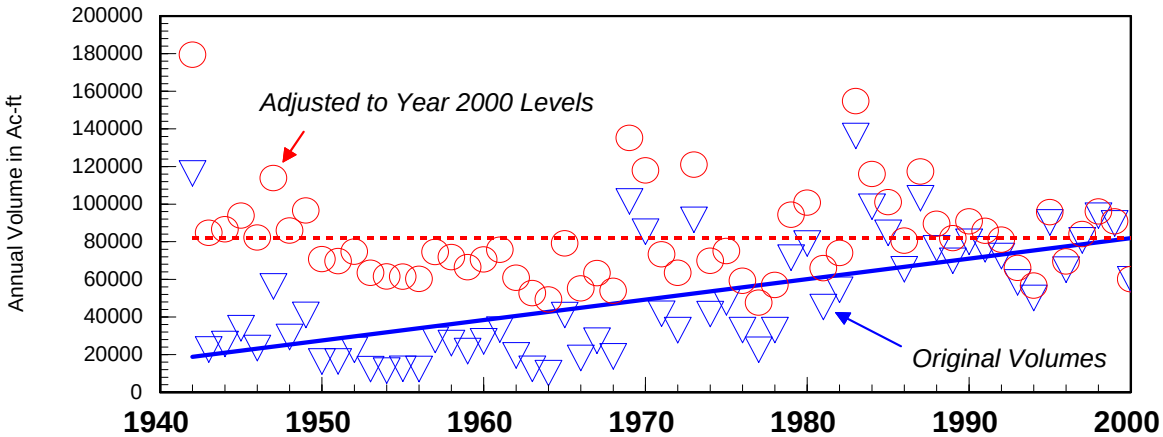


Figure 2 – South Platte River at Denver gage trend analysis

Conversion of Annual Maximum Daily Flows to Instantaneous Peak Flows.

For developing flow probability relationships on the South Platte River at the Denver, Henderson, Kersey, and Julesburg locations, the largest annual daily flow values derived from the HEC-5 model results need to be converted to an instantaneous peak flow. This was accomplished with a trend analysis by taking the observed period of record flow data for each location and plotting the annual instantaneous peak flow to the daily mean flow that occurred on that same day as shown in Figure 3 for the Henderson gage. A linear regression equation was derived for the Henderson and Kersey gages. For Julesburg, a ratio of the observed peak flow to the observed mean daily flow was averaged over the period of record and applied to each of the largest annual daily flow values from the HEC-5 model. Only the period of record after Chatfield Reservoir was built was used, which was 26 years. The regression equation was then applied to the annual peak daily flow that occurred from the HEC-5 modeling results for each location. The formula used is listed below and the regression parameters are listed in Table 5

$Y_{max} = mx + b$ where,

Y_{max} = Annual maximum instantaneous peak discharge
m = Annual maximum daily flow
x = Factor
b = Constant

The linear regression did not give satisfactory results for the Denver gage. Therefore, a multiple linear regression analysis was performed resulting in a better fit to the data. HEC's Multiple Linear Regression Program (MLRP) (HEC,1970) was utilized and the following regression equation developed.

$$Y_{DenMax} = 10^{\wedge(0.604*\log10(m)+(1.91))}$$ where,

Y_{DenMax}= Annual maximum instantaneous peak discharge for Denver
m= Annual maximum daily flow

Table 5
Factors to convert mean daily to peak discharges

Gage Location	Factor (x)	Constant (b)	R^2
Denver	-----	------	
Henderson	1.535	2988	0.70
Kersey	0.929	2414	0.89
Julesburg	1.060	0	-----

For reservoir outflows, the annual peak daily flow was not converted to an instantaneous peak flow since reservoir operations are normally made on a daily basis with the outflow from the reservoir set once a day. Since the outflow would not likely change during the course of the day under most conditions, the daily flow and instantaneous peak values would be the same.

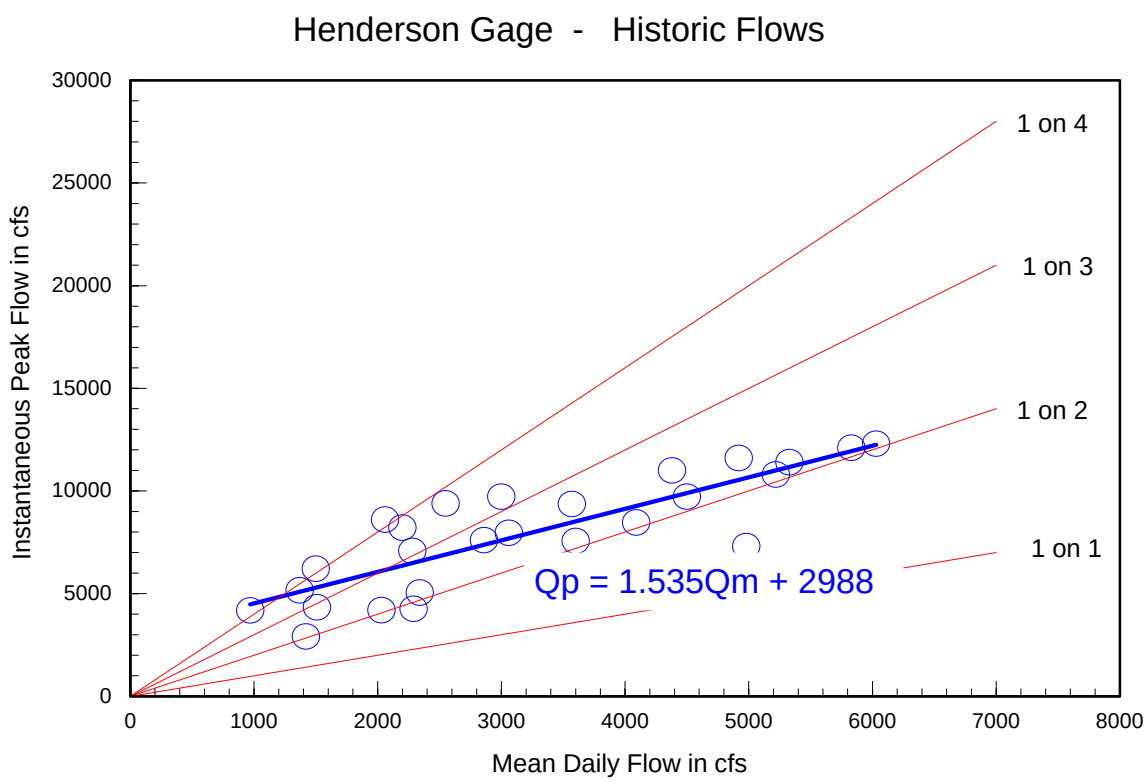


Figure 3 - Relationship between Mean Daily Flow and Instantaneous Peak Flow

Model of TriLakes Reservoir System.

To simulate the operation of Chatfield, Bear Creek and Cherry Creek Reservoirs, an HEC-5 (HEC,1986) model was setup. HEC-5 was developed by the Corp's Hydrologic Engineering Center (HEC) and is designed to assist in planning studies for evaluating flood control and conservation storage requirements for each project in a system of reservoirs. It can also be used to evaluate the effects of changes in operational criteria on downstream flows and on other reservoirs within the system. Reservoir simulation is accomplished by simulating the sequential operation of a system of reservoirs of any configuration using synthetic floods or historical streamflow records.

Demands can be minimum channel flows, diversion requirements, and energy requirements. Demands can be specified at the reservoir and at downstream locations (called Control Points). Physical reservoir constraints define the available storage for flood control and conservation purposes and maximum outlet capability for a multiple reservoir system. Operational constraints can include maximum non-damaging flows and reservoir release rate-of-change. The simulation process determines the reservoir release at each time step and the resulting downstream flows.

The model was configured with Chatfield, Bear Creek, and Cherry Creek Reservoirs as upstream boundaries. Control points downstream of the reservoirs for the flood control operation targets were established on the South Platte River at the Denver, Henderson, Kersey, and Julesburg streamflow gages. Physical data for each of the reservoirs were taken from the Water Control Manuals and configured with the elevation-area-capacity relationships. A combined discharge rating curve was developed for the outlet works and the spillway. Historical inflow data for the three (3) reservoirs are included along with incremental flow between the control points on the South Platte River. Rules curves were based on the Water Control manuals for the three dams. Elevation-area-capacity relationships and outlet rating curve relationships are shown in Appendix H-B.

The routing of flows through the various reaches were accomplished using the modified puls method. The storage outflow relationships were furnished by the Hydraulics Section and were developed using the HEC-2 (HEC,1995) backwater model for the South Platte River and tributaries. Storage outflow relationships were derived for the following reaches and are shown in Appendix H-B.

1. Chatfield Dam to Bear Creek
2. Bear Creek Dam to confluence with the South Platte
3. Bear Creek confluence to Denver gage
4. Cherry Creek Dam to confluence with the South Platte
5. Denver gage to Henderson gage
6. Henderson gage to Kersey gage
7. Kersey gage to Julesburg gage

The HEC-5 model was configured with historical daily flow data from January 1, 1942 through December 31, 2000. Evaporation data for each reservoir was based on the average monthly values for Cherry Creek Dam for its period of record 1959 through 1999. Average monthly rainfall values for the Denver Stapleton Airport precipitation gage for the period of record from 1948 to 2002 were subtracted from the monthly evaporation values and applied to all three dams. Monthly evaporation data, rainfall data and the final values used in the model are shown in Table 6.

The model was utilized with a forecast look-ahead period of 24 hours assuming perfect foreknowledge of downstream flow conditions at the Denver control point and reservoir inflows. This allows the cutting back on outflows from the reservoir when downstream runoff is forecasted to exceed various thresholds.

Table 6
Average Monthly Evaporation, Rainfall and Net Evaporation (inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pan Evaporation	0.75	0.92	1.67	3.87	6.54	8.40	9.46	8.30	6.53	4.44	2.49	0.98
Lake Evaporation[1]	0.53	0.64	1.17	2.71	4.58	5.88	6.62	5.81	4.57	3.11	1.74	0.69
Precipitation	0.52	0.59	1.24	1.77	2.48	1.67	2.04	1.58	1.17	0.97	0.86	0.55
Net Evaporation[2]	0.00	0.05	-0.07	0.93	2.10	4.21	4.58	4.23	3.40	2.13	0.89	0.14

Note: [1]Lake Evaporation = Pan Evaporation*Pan Coefficient. Pan Coefficient = 0.70
[2]Net Evaporation = Evaporation– Precipitation. Used in HEC-5 model.

Historic Chatfield Releases

With the development of the HEC-5 model, it was necessary to estimate historic water supply data for release from Chatfield Reservoir. No historic water supply values were available from the local sponsor. However, there were daily reservoir release records available for Chatfield Reservoir since its construction (1976 through 2000), but these records did not differentiate between flood flow releases and historic water right releases. To account for this, historic Chatfield daily releases were compared to the daily pool elevation. If the pool was below 5432.0 ft msl and there was a release that day, then it was considered a water right release. If the pool was above 5432.0 ft msl and there was a release that day, then it was considered to be a flood control release and the water supply release was set to 0 cfs.

Since no Chatfield releases were available prior to construction of the dam, there was no way to determine what the day to day water right flows would be from the historic streamflow records on the South Platte. Water rights flows for years prior to Chatfield Dam construction were estimated based on water rights flows in years after dam construction. The average annual inflow was calculated for each year of the period of record 1942 through 2000. Water rights flows for years prior to the beginning of project operation were assumed to be similar to water rights flows in

years with similar annual average flows after project operation began. For example, the average daily flow in 1943 was 133.3 cfs prior to construction of Chatfield Reservoir. This compared to an average daily flow of 139.2 cfs for 1989, after the construction of the dam. Therefore, calculated water right releases for 1989 were initially applied to 1943. Daily water right flows were then corrected by comparing the historic daily inflow for the pre-dam construction year to the daily water right flow for the year chosen to represent it. If the inflow value to the reservoir was at least 50 percent of the water right flow for that day, then the original water right value was used. If the inflow to the reservoir was less than 50 percent of the water right flow, then the original water right flow was reduced to twice the inflow value. Since this method lowers the overall average annual water supply values, daily flows were factored each year by the percent difference between the adjusted average annual water supply value and original average annual value taken from after the construction of the dam. Average yearly inflows, years selected for water right values, and average yearly water right flows are listed in Table H-A5 of Appendix H-A.

While the water supply estimates may not be accurate and not necessarily an indication of how water may be allocated in the future, the HEC-5 model will be able to show the relative differences when comparing the base condition for the existing multipurpose pool and the with project conditions and their potential impacts.

Model Calibration

Once the HEC-5 model was configured, it was calibrated and verified using the historical period of record of Chatfield Reservoir data from 1976 to 2000. A 24-hour time step was used. Local inflows used did not include the adjustment to the year 2000 development. Parameters adjusted to calibrate and verify the model included, the maximum daily incremental increase in releases from the reservoirs, the total daily maximum outflows from the reservoirs, and the maximum target flows at the downstream control points of Denver and Henderson. Comparisons of the observed and modeled daily pool elevations for Chatfield Reservoir and daily flows for the Denver gage are shown in Figures 4 and 5 for the 1983 high flow event, and Figures 6 and 7 for the 1995 high

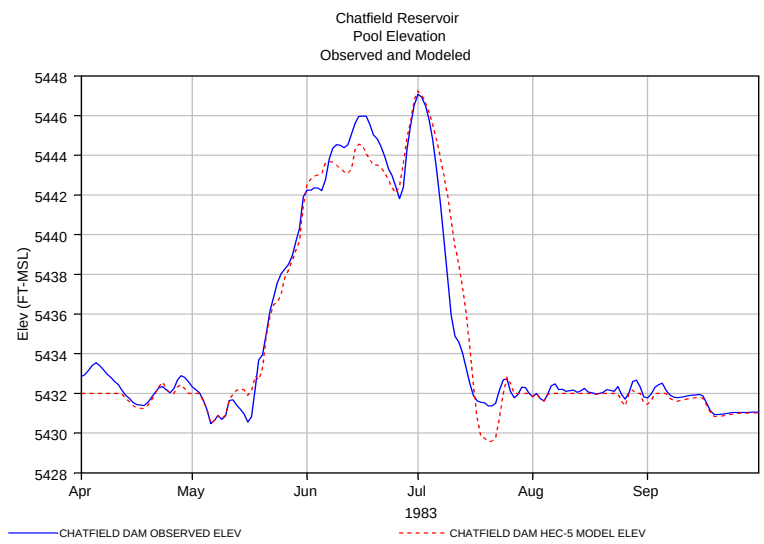


Figure 4 – Chatfield pool elevations for 1983 event.

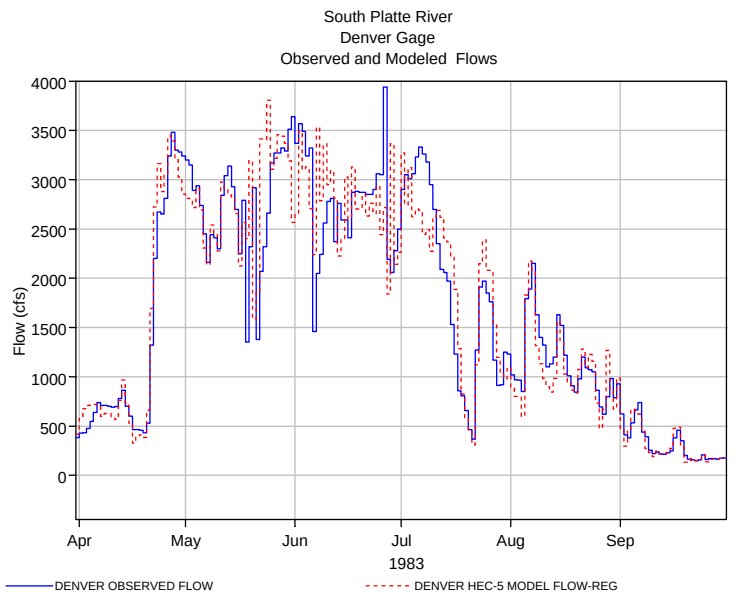


Figure 5 – South Platte flows at Denver for 1983 event.

flow event.

Over the period of record used for calibration, when Chatfield Reservoir is at or near the top of the conservation pool 5432 ft msl (which is the majority of the time), the model does a good job of replicating the pool elevations which are usually within a foot of the observed data. During high inflow years, the model did a good job of matching the peak pool elevation during the 1983 and 1995 flood events. To get the two high flow years to match the observed data, the maximum allowable outflow from Chatfield Reservoir and the maximum allowable flow at the control points at Denver and Henderson were adjusted and were not the same for each high flow event. This was seen in the observed data where the maximum reservoir outflows were below 2,900 cfs in 1983 and 3,400 cfs in 1995. Also, it appears that maximum target flows applied not only to Denver, but to Henderson, which is not a target flow location listed in the Water Control Manual. While the reservoir outflows and downstream target flows were not consistent for both high flow events, they were all below the allowable maximum flow values found in the Water Control Manual. This shows the constraints of the HEC-5 model in that the rule curves may not be followed by the dam operator in the same manner as the model. In fact, different operators would not likely make the same decisions for the same event. For instance, the model assumes perfect knowledge of potential runoff 24 hours ahead of time at the Denver or Henderson control points and makes a release decision based on that information.

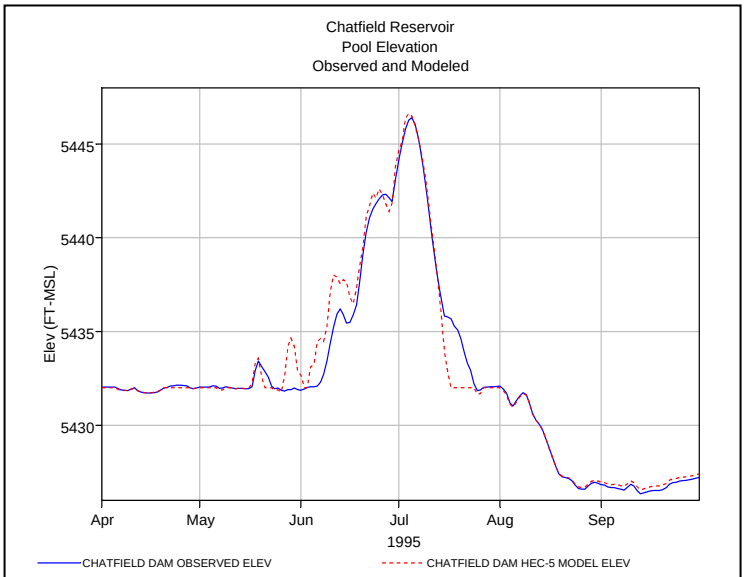


Figure 6 - Chatfield pool elevations for 1995 event.

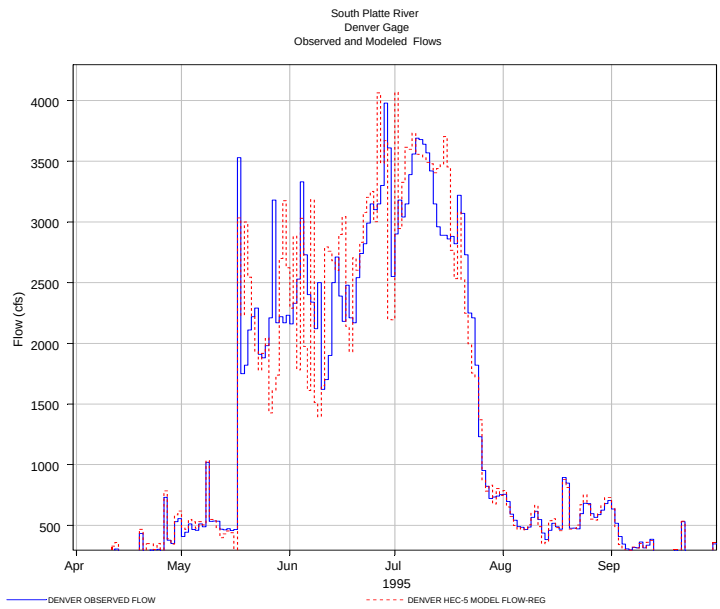


Figure 7 – South Platte flows at Denver for 1995 event.

Actual project operations are based on a number of factors including reservoir inflow, downstream flow, and weather and flow forecasts. The regulator does not have perfect knowledge of these factors into the future. Therefore, the actual operation of the reservoir will diverge from what the HEC-5 model performs. Since the prior day's decision affects the next day's decision, the model and the actual operation may continue to diverge. The HEC-5 model also cannot take into account any deviations from the rule curves that may occur, such as operating constraints of the reservoir system based on conditions downstream at locations other than the control points configured in the model.

It should be noted that in the calibration of the model, the rule curves were not always followed as spelled out by the Water Control Manuals. However, by using the same rule curves for all conditions, the relative difference between baseline conditions and the project scenarios can be shown. The affect to the reservoir and downstream conditions can then be estimated.

Baseline Conditions

The calibrated HEC-5 model was then used to establish baseline conditions. Inflows that were adjusted to current level of development (Year 2000) were configured in the model. The Denver Water Board (DWB), through the Colorado Water Conservation Board (CWCB), owns 11,000 acre-feet of storage in Chatfield Reservoir. The DWB is allowed to regulate flow of water into and out of Chatfield Reservoir between the elevations of 5432 and 5423 ft msl. The elevation may drop below 5423 ft msl in times of severe or prolonged drought conditions as reasonably determined by the CWCB. In addition, the reservoir is operated as nearly as practicable to maintain a pool of at least 5426 ft msl during the period of May 1st through August 31st of each year for outdoor recreational uses. The HEC-5 model was configured so that no water supply flows were released whenever the reservoir fell below 5423 ft msl from January through April and September through December. In addition, no water supply flows were released whenever the reservoir dropped below 5426 ft msl during the months of May thru August. The current reservoir regulation criteria listed in the Water Control Manuals for the three reservoirs was

configured in the model. Table 7 lists the calibrated models regulation criteria used as compared to the current Water Control regulation criteria. A simulation period of 1942 through 2000 was used.

From the information developed, pool and outflow duration relationships were developed for Chatfield, Bear Creek, and Cherry Creek reservoirs. Flow duration relationships were developed at the Denver, Henderson, Kersey, and Julesburg gages on the South Platte River. Duration relationships were computed using HEC's statistical computer program STATS (HEC,1987) and were computed on an annual, monthly, and seasonal basis. The seasonal was for winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec). Annual pool and outflow duration relationships for Chatfield Reservoir are shown in Figures 8 and 9 and listed in Table 8. Annual pool duration relationships for Cherry Creek and Bear Creek Reservoirs are listed in Table 9. Annual flow duration values for the South Platte River at Denver and Henderson are listed in Table 10. Duration relationships on an annual, monthly, and seasonal basis can be found in Appendix H-C for all locations.

Table 7
Comparison of Calibrated and Baseline Regulation Criteria

Location	Regulation Criteria	Calibrated Model	Water Control Manual
	Maximum allowable daily increase	Not used	500 cfs/day
Chatfield Dam	Maximum total daily outflow	2,100 / 3,100 cfs/day[1]	5000 cfs/day
	Maximum allowable daily increase	200 cfs/day	200 cfs/day
Bear Creek Dam	Maximum total daily outflow	600 cfs/day	2000 cfs/day
	Maximum allowable daily increase	200 cfs/day	500 cfs/day
Cherry Creek Dam	Maximum total daily outflow	500 cfs/day	5000 cfs/day
Denver Control Point	Target flow	3,500 / 4,200 cfs[1]	5,000 cfs
Henderson Control Point	Target flow	4,600 / 5,100 cfs[1]	n/a[2]
Kersey Control Point	Target flow	7,000 cfs	n/a
Julesburg Control Point	Target flow	8,000 cfs	n/a

Note: [1]First value used for the 1983 high flow event. Second value used for the 1995 high flow event
[2] n/a – The Water Control Manual only has target flows at Denver

Pool probability relationships were developed for Chatfield, Bear Creek, and Cherry Creek reservoirs based on the Weibull plotting position. The Weibull plotting position is a graphical method of a frequency analysis based on the number of years of observed annual maximum pool records. The curves were ocularly fitted to the data. The pool probability curve for Chatfield Reservoir is shown in Figure 10. Pool values for the 2 through 500-year return period are listed in Table 11 for all three reservoirs.

For the reservoir outflow probability relationships, since the flows were controlled releases from the reservoir, the log-Pearson Type III distribution was not used. Instead, the annual maximum outflows were plotted based on the Weibull

plotting position. A curve was then drawn through the data up to the maximum outflow allowed by the Water Control Manual. The curve was then straight lined at the maximum allowed outflow until the frequency at which the pool probability curve would reach the crest of the uncontrolled spillways. Since the elevations of the spillway crests were beyond the 500-year event for all three reservoirs based on the pool probability curves, the flow was assumed to stay at the maximum outflow allowed. The Chatfield Reservoir outflow probability curve is shown in Figure 11. Reservoir outflows for the 2- through 500-year return period are listed in Table 12 for all three reservoirs.

On the South Platte River, flow probability relationships were developed at the Denver, Henderson, Kersey, and Julesburg gages. The annual maximum daily flow first had to be converted to an instantaneous peak flow utilizing the regression equations discussed in the section titled, *Conversion of Annual Maximum Daily Flows to Instantaneous Peak Flows* and the parameters listed in Table 5. Flow probability relationships were then computed based on the methodology presented in Bulletin 17B (WRC,1981) utilizing the log-Pearson type III distribution. A top-half analysis was performed on the Denver and Henderson gage locations which gave a better fit to the historical peaks when plotted graphically. A top-half analysis only utilizes the highest 50% of annual peak discharges in the log Pearson Type III analysis. Flow probabilities for the South Platte River are shown graphically in Figures 12 through 15 and listed in Table 12 for all four locations.

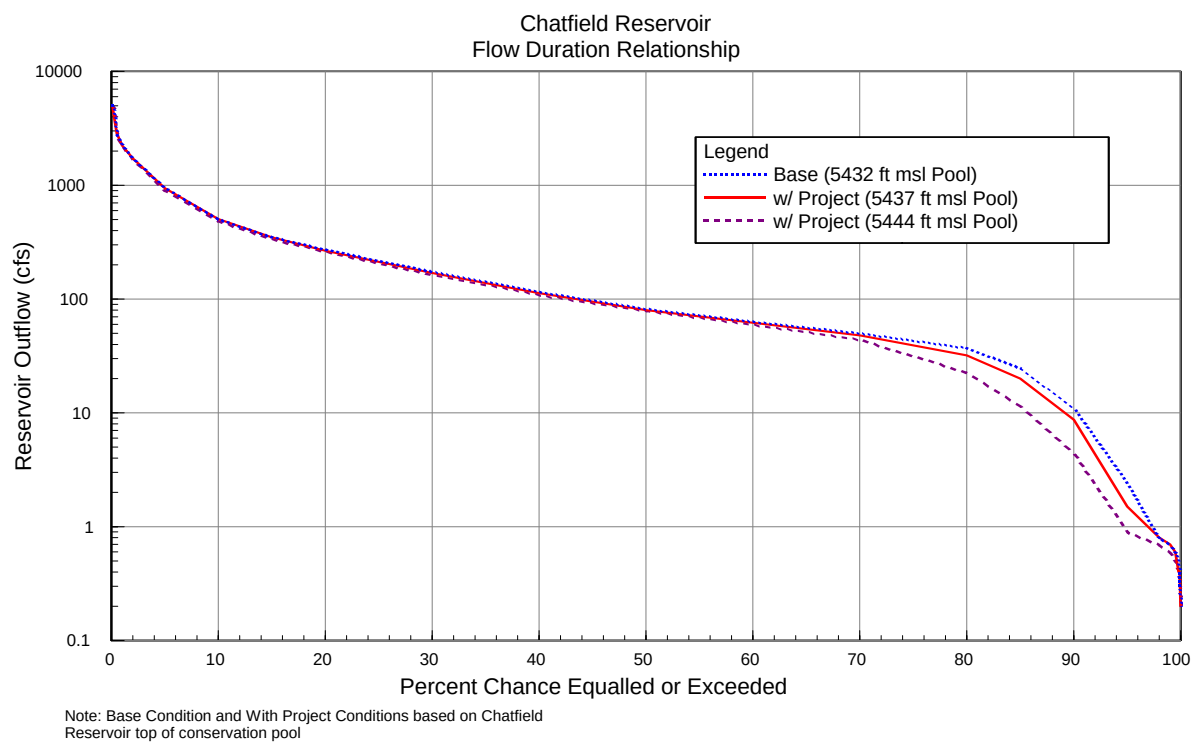
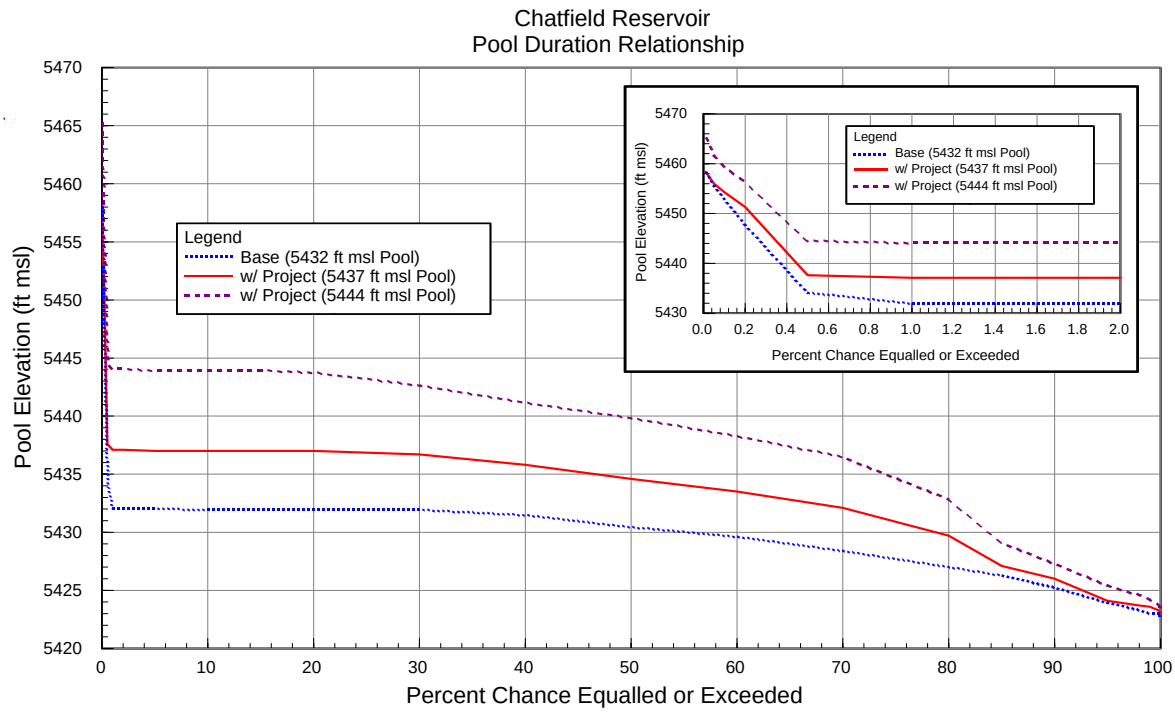
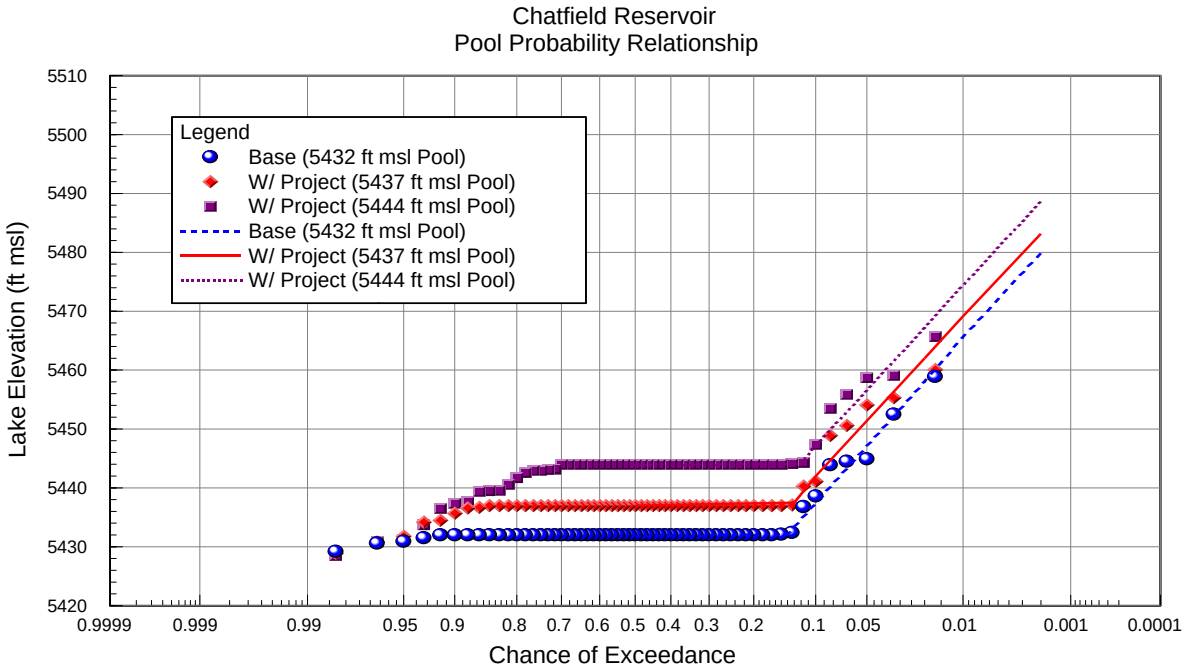


Figure 8 – Flow Duration Relationship – Chatfield Reservoir



Note: Base Condition and With Project Conditions based on Chatfield Reservoir top of conservation pool

Figure 9 – Pool Duration Relationship – Chatfield Reservoir



Note: Base Condition and With Project Conditions based on Chatfield Reservoir top of conservation pool

Figure 10 – Chatfield Reservoir Pool Probability Relationship

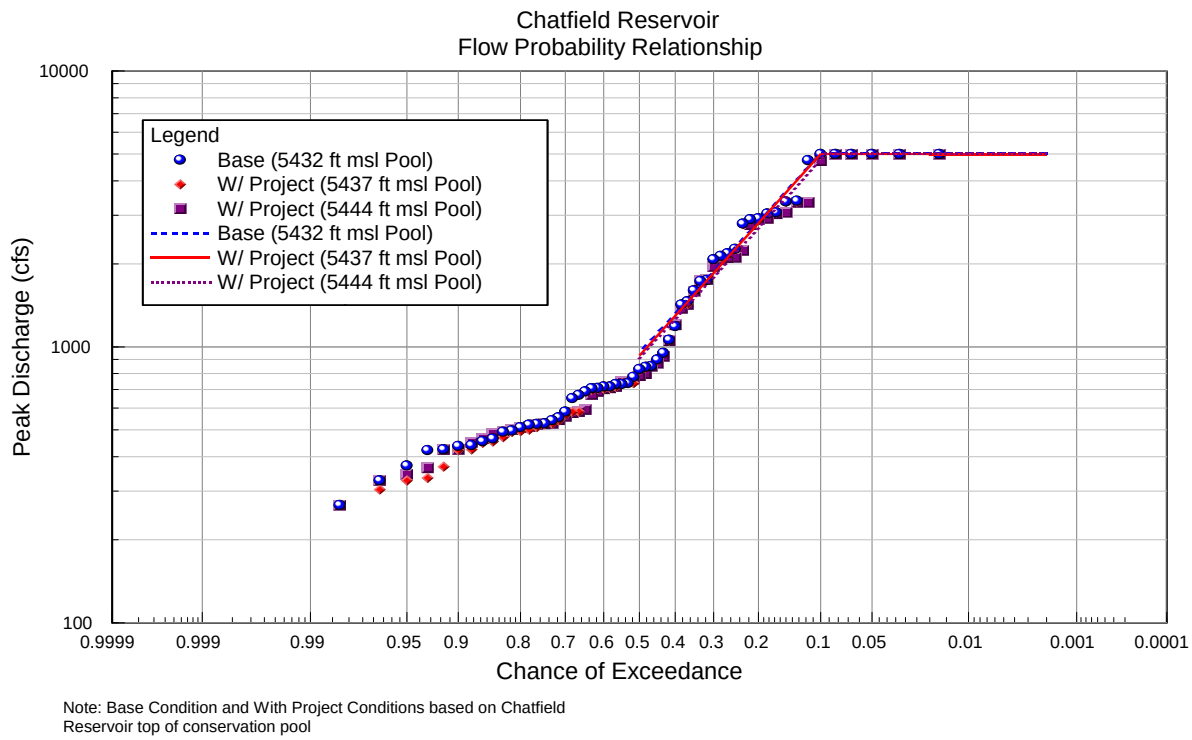


Figure 11 - Chatfield Reservoir Flow Probability Relationship

With Project Conditions.

With baseline conditions established, two different storage reallocation alternatives were evaluated for Chatfield Reservoir. A conservation pool raise of 5 feet and 12 feet for flood control storage reductions of 7,700 and 20,600 acre-feet, respectively. No evaluation was performed of a potential conservation pool raise at Bear Creek or Cherry Creek Reservoirs. The simulation was evaluated using the existing regulation criteria found in the Water Control Manuals. Daily water right storable flows and releases for the pool reallocations were furnished by the State of Colorado for the period of record and are listed in Appendix H-B as average monthly flow data. Values given are for the conservation pool raise of 12 feet. For the 5 foot raise, the flow values were reduced by 63.0 percent which is the ratio of the potential additional conservation pool storage of 7,700 and 20,600 acre-feet for the 5 and 12 foot conservation pool raise, respectively. Flows Daily values were imported to HEC-DSS and configured in the HEC-5 model. Water supply flows for Denver and other senior water right users were the same as those included in the calibration and base condition models. For modeling the with project conditions, the new water supply users were separated into two groups. The first group will release their water right allocations from the reservoir and divert it further downstream on the South Platte River while the second group will divert their water directly from Chatfield Reservoir and not release it downstream. The entities were divided into the following:

Downstream Users (water sent downstream thru Chatfield)

City of Aurora
City of Brighton
Central Colorado Water Conservancy District
Western Mutual Ditch Company
Colorado Division of Parks and Outdoor Recreation
Denver Botanic Gardens

Upstream Users (water diverted out of Chatfield and not routed downstream)

South Metro Water Supply Authority
Parker Water and Sanitation District
Centennial Water and Sanitation District
Town of Castle Rock
Roxborough Metropolitan District
Castle Pines North Metropolitan District
Castle Pines Metropolitan District
Hock Hocking LLC.
Perry Park Country Club
Central Colorado Water Conservancy District

For Upstream Users, the HEC-5 model was configured with the water supply diverted directly out of Chatfield and not routed downstream. For water supply flows that are sent downstream from Chatfield, the Cities of Aurora and Brighton, Central Colorado Water Conservancy District and Western Mutual Ditch Company are diverted out of the South Platte River between the Henderson and Kersey gages. Water supply flows for The Colorado Division of Parks and Outdoor Recreation and the Denver Botanic Gardens are left in-stream and not diverted from the model.

For each with project condition evaluated, pool and outflow probability and annual, monthly, and seasonal pool duration relationships were developed for each reservoir. Annual pool and outflow durations for Chatfield Reservoir are listed in Table 7. Annual pool durations for Cherry Creek and Bear Creek Reservoirs are listed in Table 8. Pool probability relationships for all three reservoirs are listed in Table 10. Annual, monthly and seasonal flow duration relationships were developed at each of the downstream control points on the South Platte, including Denver and Henderson. Annual flow duration values are listed in Table 9 for Denver and Henderson. Flow probability relationships were developed for these locations after converting the annual maximum daily flow to an instantaneous peak flow and are shown on Figures 11 through 14 and listed in Table 11. Annual, monthly, and seasonal pool and flow duration relationships for the three reservoirs and the control points downstream on the South Platte are listed in Appendix H-C.

Table 8
Chatfield Reservoir Annual Duration Relationships
Base and With Project Conditions

Percent of Time Equaled or Exceeded	Chatfield Reservoir Pool Elevation (ft msl)			Chatfield Reservoir Outflow (cfs)		
	Base (5432.0)[1]	w/ Project (5437.0)[1]	w/ Project (5444.0)[1]	Base (5432.0)[1]	w/ Project (5437.0)[1]	w/ Project (5444.0)[1]
0.01	5458.5	5458.4	5465.3	5000	5000	5000
0.05	5455.7	5456.0	5461.8	5000	5000	5000
0.1	5452.9	5454.3	5459.4	5000	5000	5000
0.2	5447.9	5451.3	5456.5	4496	4289	4734
0.5	5434.1	5437.6	5444.6	2799	2849	2763
1	5432.1	5437.1	5444.1	2259	2240	2208
2	5432.1	5437.1	5444.1	1741	1721	1700
5	5432.1	5437.0	5444.0	958	942	910
10	5432.0	5437.0	5444.0	508	505	488
15	5432.0	5437.0	5444.0	354	349	342
20	5432.0	5437.0	5443.8	271	266	262
30	5432.0	5436.7	5442.7	175	170	165
40	5431.5	5435.8	5441.2	117	113	109
50	5430.5	5434.6	5439.9	83	80	79
60	5429.6	5433.5	5438.3	64	62	60
70	5428.4	5432.1	5436.5	51	48	44
80	5427.0	5429.7	5432.9	37	32	23
85	5426.3	5427.1	5429.1	25	20	11.6
90	5425.3	5426.0	5427.3	11	8.7	4.4
95	5424.0	5424.1	5425.5	2.4	1.5	0.9
98	5423.3	5423.7	5424.6	0.8	0.8	0.7
99	5423.0	5423.6	5424.3	0.7	0.7	0.6
99.5	5423.0	5423.4	5424.0	0.6	0.6	0.5
99.8	5423.0	5423.3	5423.8	0.5	0.4	0.4
99.9	5423.0	5423.2	5423.6	0.4	0.4	0.3

Note: [1]Elevation at Chatfield Reservoir top of conservation pool.

Table 9
Bear Creek and Cherry Creek Reservoirs
Annual Pool Duration Relationships
Base and With Project Conditions

Percent of Time Equaled or Exceeded	Bear Creek Reservoir Pool Elevation (ft msl)			Cherry Creek Reservoir Pool Elevation (ft msl)		
	Base (5432.0)[1]	w/ Project (5437.0)[1]	w/ Project (5444.0)[1]	Base (5432.0)[1]	w/ Project (5437.0)[1]	w/ Project (5444.0)[1]
0.01	5589.7	5590.5	5590.5	5559.8	5559.8	5560.8
0.05	5580.1	5583.4	5583.2	5554.1	5556.1	5555.1
0.1	5572.9	5577.8	5576.2	5551.2	5551.5	5552.0
0.2	5565.8	5567.0	5566.6	5550.4	5550.3	5550.2
0.5	5562.1	5562.2	5562.1	5550.1	5550.1	5550.1
1	5561.4	5561.4	5561.4	5550.1	5550.1	5550.1
2	5560.9	5560.9	5560.9	5550.1	5550.1	5550.1
5	5560.3	5560.3	5560.3	5550.1	5550.1	5550.1
10	5559.8	5559.8	5559.8	5550.0	5550.0	5550.0
15	5559.3	5559.3	5559.3	5550.0	5550.0	5550.0
20	5559.0	5559.0	5559.0	5550.0	5550.0	5550.0
30	5558.6	5558.6	5558.6	5550.0	5550.0	5550.0
40	5558.4	5558.4	5558.4	5550.0	5550.0	5550.0
50	5558.3	5558.3	5558.3	5550.0	5550.0	5550.0
60	5558.3	5558.3	5558.3	5550.0	5550.0	5550.0
70	5558.2	5558.2	5558.2	5549.8	5549.8	5549.8
80	5558.2	5558.2	5558.2	5549.5	5549.5	5549.5
85	5558.1	5558.1	5558.1	5549.3	5549.3	5549.3
90	5558.1	5558.1	5558.1	5549.1	5549.1	5549.1
95	5558.1	5558.1	5558.1	5548.9	5548.9	5548.9
98	5558.0	5558.0	5558.0	5548.8	5548.8	5548.8
99	5558.0	5558.0	5558.0	5548.7	5548.7	5548.7
99.5	5558.0	5558.0	5558.0	5548.7	5548.7	5548.7
99.8	5558.0	5558.0	5558.0	5548.7	5548.7	5548.7
99.9	5558.0	5558.0	5558.0	5548.6	5548.6	5548.6

Note: [1]Elevation at Chatfield Reservoir top of conservation pool.

Table 10
South Platte River Annual Duration Relationships
Base and With Project Conditions

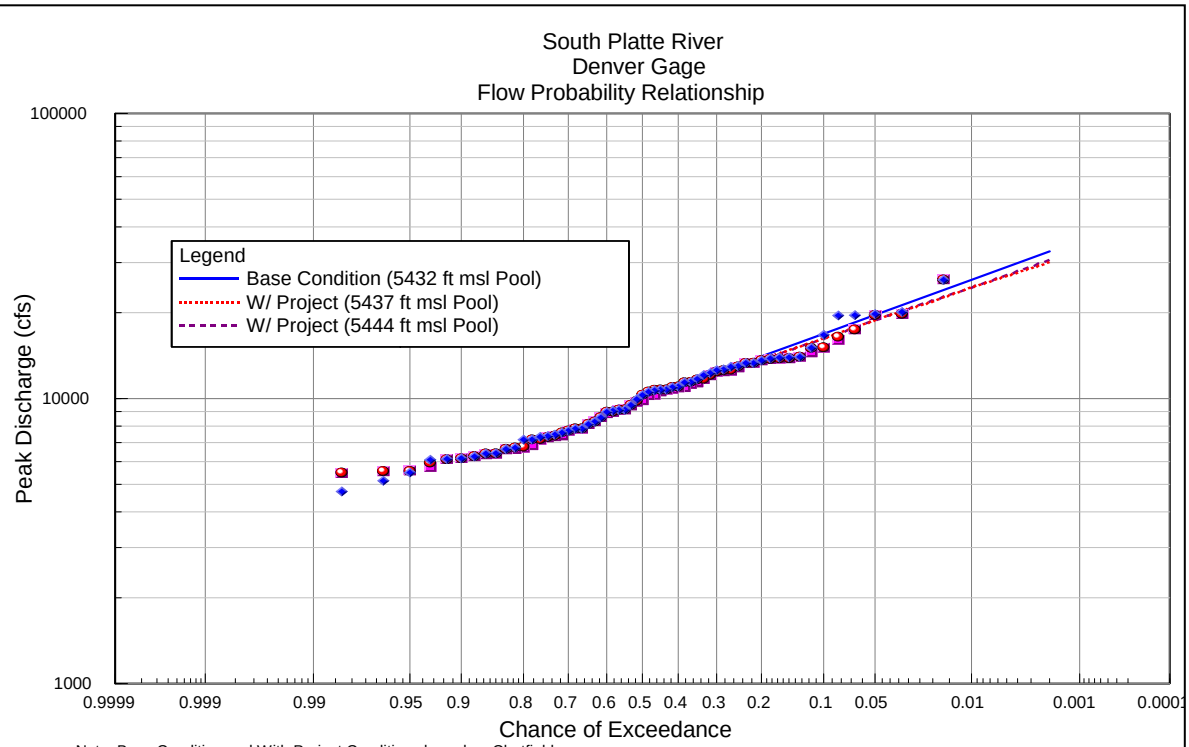
Percent of Time Equaled or Exceeded	South Platte River at Denver Gage (cfs)			South Platte River at Henderson Gage (cfs)		
	Base (5432.0)[1]	w/ Project (5437.0)[1]	w/ Project (5444.0)[1]	Base (5432.0)[1]	w/ Project (5437.0)[1]	w/ Project (5444.0)[1]
0.01	8668	8679	8664	16676	14768	14768
0.05	6775	6803	6776	11159	10969	10855
0.1	6188	6220	6190	9730	9401	9264
0.2	5575	5609	5569	8199	8135	8010
0.5	4507	4527	4476	6343	6419	6297
1	3575	3557	3500	5033	5092	4990
2	2589	2563	2524	3797	3796	3719
5	1467	1440	1407	2259	2246	2220
10	844	836	813	1348	1343	1328
15	595	589	582	976	973	960
20	474	471	464	773	770	762
30	332	329	326	570	565	562
40	248	245	242	454	450	445
50	198	195	193	373	370	366
60	165	162	159	311	308	305
70	139	137	135	253	251	249
80	115	113	112	203	201	201
85	103	101	100	171	170	170
90	88	87	85	137	136	135
95	67	67	64	101	100	99
98	44	44	42	73	72	70
99	28	30	28	56	56	52
99.5	18	18	18	41	40	38
99.8	13	13	13	26	24	23
99.9	11	11	11	18	17	16

Note: [1]Elevation at Chatfield Reservoir top of conservation pool.

Table 11
Pool Probability - Chatfield, Bear Creek and Cherry Creek Reservoirs
Comparison of Baseline and With Project Conditions

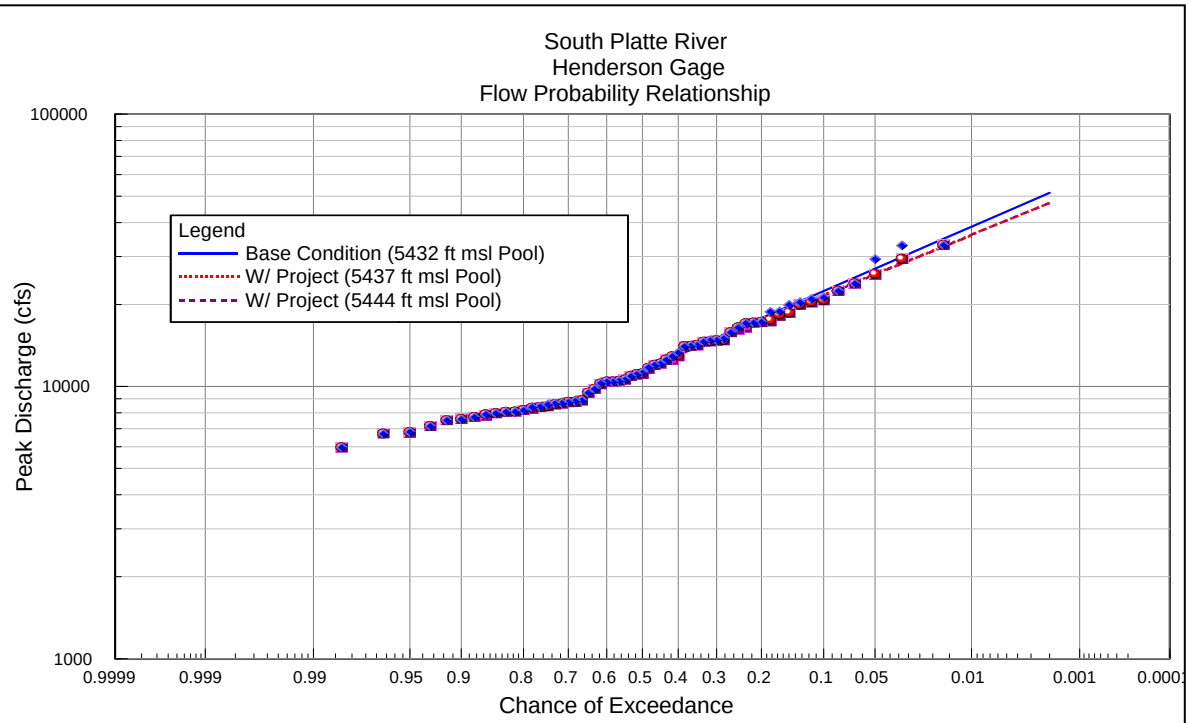
Location	Conservation Pool[1] (ft msl)	Pool Probabilities (ft msl)				
		2-Year	10-Year	50-Year	100-Year	500-Year
	5432	5432.0	5437.5	5458.1	5465.5	5479.7
	5437	5437.0	5442.0	5462.0	5469.2	5483.2
Chatfield Reservoir	5444	5444.0	5447.2	5467.1	5474.3	5488.5
	5432	5560.0	5564.2	5594.0	5606.0	5628.0
	5437	5560.0	5564.2	5594.0	5606.0	5628.0
Bear Creek Reservoir	5444	5560.0	5564.2	5594.0	5606.0	5628.0
	5432	5550.0	5550.5	5563.1	5567.6	5576.7
	5437	5550.0	5550.7	5563.1	5567.6	5576.7
Cherry Creek Reservoir	5444	5550.0	5550.7	5563.1	5567.6	5576.7

[1] Conservation Pool is for Chatfield Reservoir



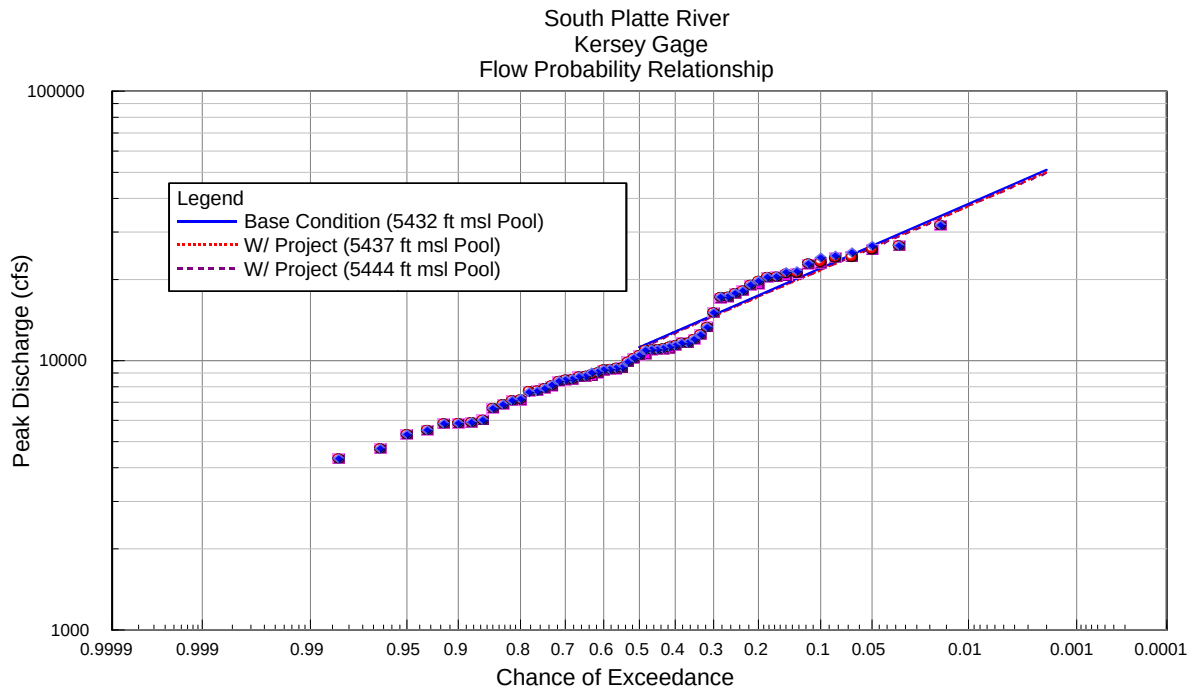
Note: Base Condition and With Project Conditions based on Chatfield Reservoir top of conservation pool

Figure 12 – South Platte River Flow Probability Relationship - Denver



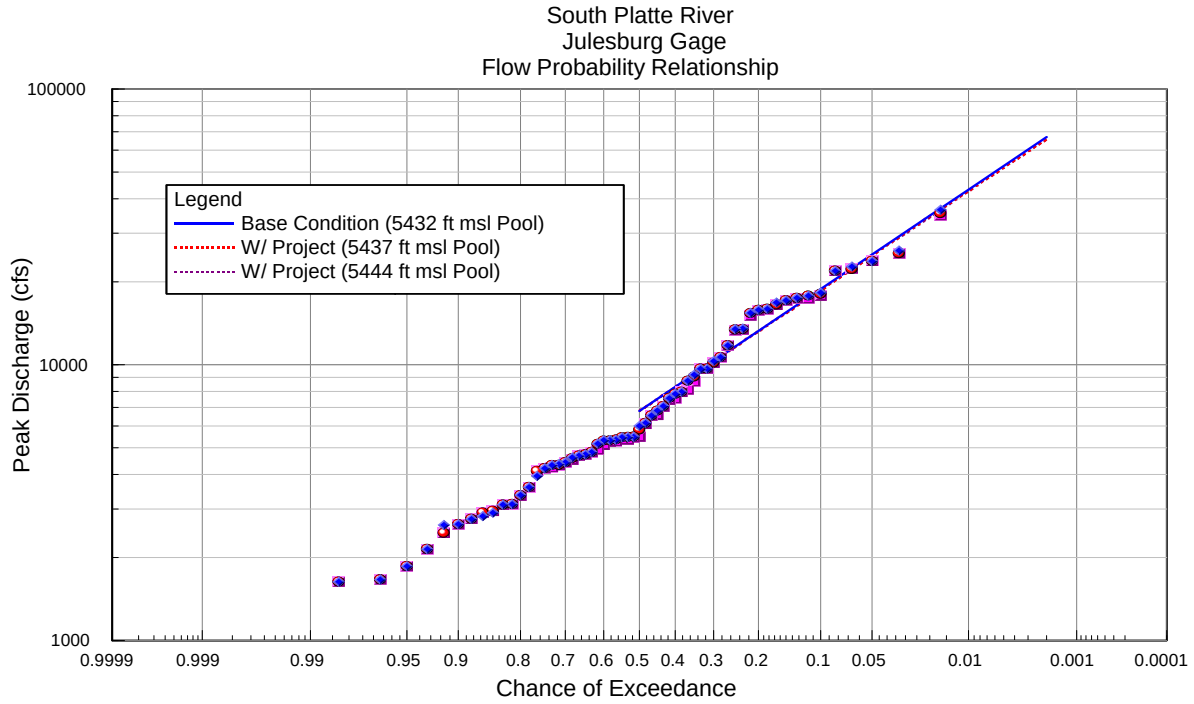
Note: Base Condition and With Project Conditions based on Chatfield Reservoir top of conservation pool

Figure 13 - South Platte River Flow Probability Relationship - Henderson



Note: Base Condition and With Project Conditions based on Chatfield Reservoir top of conservation pool

Figure 14 - South Platte River Flow Probability Relationship - Kersey



Note: Base Condition and With Project Conditions based on Chatfield Reservoir top of conservation pool

Figure 15 - South Platte River Flow Probability Relationship - Julesburg

Table 12
Peak Discharge Probability - South Platte River Basin, Colorado
Comparison of Baseline and With Project Conditions

Location	Conservation Pool[1] (ft msl)	Peak Discharge Probabilities (cfs) 2-Year	10-Year	50-Year	100-Year	500-Year
	5432	950	4,300	5,000	5,000	5,000
	5437	950	3,800	5,000	5,000	5,000
Chatfield Releases	5444	950	4,000	5,000	5,000	5,000
	5432	230	790	1,750	2,000	2,000
	5437	230	790	1,750	2,000	2,000
Bear Creek Releases	5444	230	790	1,750	2,000	2,000
	5432	150	1,250	5,000	5,000	5,000
	5437	150	1,250	5,000	5,000	5,000
Cherry Creek Releases	5444	150	1,250	4,100	5,000	5,000
	5432	9,800	16,200	21,900	24,300	30,100
	5437	9,700	16,100	21,900	24,300	30,300
Denver	5444	9,700	16,200	22,000	24,500	30,600
	5432	11,600	21,800	31,900	36,500	47,900
	5437	11,500	21,700	31,800	36,400	47,800
Henderson	5444	11,500	21,800	32,100	36,800	48,600
	5432	11,200	21,800	32,600	37,500	50,000
	5437	11,200	21,700	32,400	37,400	49,800
Kersey	5444	11,100	21,700	32,400	37,300	49,800
	5432	6,800	18,600	34,200	42,400	65,500
	5437	6,700	18,500	34,100	42,200	65,300
Julesburg	5444	6,700	18,400	33,800	41,900	64,800

[1] Conservation Pool is for Chatfield Reservoir

Discussion of Results.

There was a vast amount of data generated by this analysis that will be used for assessing the impacts to the flood control, fisheries and wildlife, and recreation both, upstream and downstream of Chatfield Reservoir. This discussion will address general trends based on the annual results when comparing the base and the with project conditions.

For Chatfield Reservoir, obviously increasing the top of the conservation pool for the project conditions increased the percent of time the reservoir was at an elevation higher than the base condition pool of 5432.0. A better way of presenting the data would be to focus on the percent of time the top of conservation pool is equaled or exceeded. For the base condition, the pool was at or above the 5432.0 ft msl pool 30 percent of the time on an annual basis for the period of record. For the two with project conditions, the pool was at or above the top of conservation pool 5437.0 ft msl and 5444.0 ft msl for 20 and 15 percent of the time, respectively. At five feet below the top of conservation pool, the reservoir would equal or exceed that elevation 80 percent of the time for base conditions. For the with project conditions,

the pool would be within 5 feet of the top of conservation pool just over 70 percent of the time for the 5437 pool and just under 60 percent of the time for the 5444 pool.

As shown in Table 8, releases from Chatfield into the South Platte River would decrease for the with project conditions when compared to the base conditions with the exception of flow durations that are equaled or exceeded less than 0.5 percent of the time on an annual basis for the 5437 pool and 0.2 percent for the 5444 pool. Releases decreased for with project conditions due in part to the new water supply needs being directly removed from Chatfield without being released downstream on the South Platte. This is coupled with the fact that there is no additional runoff being added from the South Platte River basin upstream of Chatfield, only additional water supply requirements. Also, since Chatfield's pool is below the top of conservation pool more often for the with project conditions, there is a chance that there will be available storage to hold the water instead of passing it through the reservoir if it's in the flood control pool or needed to meet water supply requirements downstream.

Corresponding to the decrease in releases from Chatfield, annual flow durations for downstream on the South Platte River (shown in Table 10) show a slight reduction for the with project conditions when compared to the base condition with the exception of some of the extreme flow events with a 0.5 percent chance of equaling or exceeding. At Denver, for a flow of 198 cfs, which is equaled or exceeded 50 percent of the time, the flow is reduced by 5 cfs (or -2.5%) for the with project condition of a 5444 pool when compared to the base condition. At Henderson, the 50 percent equaled or exceeded flow of 373 cfs is lowered by 7.0 cfs or -1.9%

For pool probabilities, the 100-year pool elevation for Chatfield Reservoir is 5465.5 ft msl for the base condition as shown in Table 11. Increasing the top of conservation pool to 5437.0 ft msl resulted in a 100-year pool of 5469.2 ft msl or an increase of 3.7 feet when compared to the base condition. For the 5444 pool condition, the 100-year pool was 5474.3 ft msl, or an increase of 8.8 feet when compared to the base condition.

Overall for Chatfield Reservoir, the base condition, the 5437 and 5444 pools have nearly identical flow probability relationships as listed in Table 12. The with project condition of the 5437 and 5444 pools had slightly lower outflow values for the 10-year return periods. The 50-, 100-, and 500-year Chatfield outflows are all 5,000 cfs for both, the base condition and the two with project conditions. As was discussed earlier in this write-up, this is due to the releases being constrained to a maximum allowable outflow of 5,000 cfs until the pool reaches the uncontrolled spillway crest.

For Cherry Creek and Bear Creek Reservoirs, there is minimal impact to both, pool elevations and reservoir releases for the with project conditions (See Tables 11 and 12, respectively). The only impact was just a slight decrease in flows for Cherry Creek for the 10- and 50-year return period for the with project condition of a 5444.0 top of conservation pool at Chatfield. This is due to a small change in the priority of

releases between Cherry Creek and Chatfield Reservoirs that was dependent upon conditions in the reservoirs during high flow periods for the with project conditions.

On the South Platte River downstream of Chatfield Reservoir, the with project conditions slightly lowered the flooding potential at the two lower control points, Kersey, and Julesburg for the 10- through 500-year events. Flows at the Denver gage either stayed the same or slightly increased for the with project condition of 5444 pool. For instance, from Table 12, when compared to base condition, the 100-year discharge at the Denver gage goes from 24,300 cfs to 24,300 cfs for the 5437 pool (0.0 %) and 24,500 cfs for the 5444 pool (0.8%). These differences are considered negligible and would not warrant any changes in existing flood frequency criteria used for flood plain regulation The 2-year discharges either stayed the same or dropped slightly for the with project conditions.

DEVELOPMENT IN THE FLOOD POOL

If reallocation of part of the flood control pool at Chatfield Reservoir occurs, then any development of facilities for the Recreation Mitigation Plans will be subject to the Corp's Northwest Division's NWD Policy for development proposals in Corps Reservoir lands, NWDR 1110-2-5.

The hydrologic analysis was reevaluated to insure that the revised pool elevations for the reallocation of storage in Chatfield Reservoir are consistent with those defined in NWDR 1110-2-5. The pool elevations defined in NWDR 1110-2-5 for Chatfield Reservoir were derived from both historical pool elevations and modeled results. This differs from the hydrologic analysis for the Chatfield Reallocation Study which was based on modeled results only and results were not adjusted for historic pool elevations. To account for this, the reallocated pools of 5437 ft. msl and 5444 ft. msl were adjusted by assuming that the reservoir would be operated similar to what has been observed historically. Final elevations are shown in Table 13. This results in a rise in the 10-year and 100-year pool elevations and a reduction in the 50-year pool when compared to modeled only values from the Chatfield Reallocation Study. The primary reason for this difference is the model simulation studies included a maximum release of 5,000 cfs while actual historical releases have not exceeded 3,350 cfs.

Table 13
Chatfield Reservoir
NWDR 1110-2-5 for Chatfield Reallocation Pool Elevations

Top of Conservation Pool	Existing (5432)	w/ Project (5437.0	w/ Project (5444.0)
10-Year Pool Level (Zone 1)	5444.5	5448.2	5453.7
50-Year Pool Level (Zone 2)	5456.0	5458.9	5463.7
100-Year Pool Level (Zone 3)	5481.0	5483.1	5486.4

Elevation shown should be used for The Recreation Mitigation Plans for the Chatfield Reallocation Study per NWDR 1110-2-5.

OBSERVATIONS

The purpose of this study was to perform a hydrologic evaluation of the potential impacts to flood control, fisheries and wildlife, and recreation both, upstream and downstream of Chatfield Reservoir due to the potential reallocation of storage from flood control to multi-purpose use. This analysis also included quantifying the potential impacts to Cherry Creek and Bear Creek Reservoirs. A summary of the model development and findings are as follows:

- There were no historic water supply records available for Chatfield Reservoir and had to be estimated.
- Local inflows downstream of Chatfield Reservoir were adjusted to year 2000 level of development for the period of record to account for urbanization in the basin. No such adjustment was necessary upstream of any of the three reservoirs.
- During the calibration of the model, it was shown that the rule curves are not always strictly adhered to since they cannot anticipate every situation that may arise during flooding nor allow for engineering judgment.
- While both the historic and potentially new water supply estimates may not be accurate and not necessarily an indication of how water may be allocated in the future, the HEC-5 model was able to show the relative differences when comparing the base condition for the existing multipurpose pool and the with project conditions and their potential impacts.
- The pool in Chatfield Reservoir will be below the top of the conservation pool more often and will experience more fluctuation for the with project conditions.
- Less flow will be released from Chatfield to the South Platte River.
- Peak flood flows downstream of Chatfield on the South Platte River either stay the same or are slightly lower for the 2- thorough 500-year events for both, the 5437 and 5444 pools.
- The project conditions have minimal or no impact on Cherry Creek and Bear Creek pool elevations and reservoir releases.

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APPENDIX H-A

INCREMENTAL INFLOW ADJUSTMENT TO YEAR 2000 DEVELOPMENT

ANNUAL AVERAGE DAILY INFLOW, YEAR USED TO DEVELOP WATER RIGHT DEMANDS, AND ESTIMATED HISTORIC WATER RIGHT DEMANDS

SOUTH PLATTE RIVER

DENVER, HENDERSON, KERSEY, AND JULESBURG REACHES

Table H-A-1

Incremental Inflow - Denver Reach

Inflows adjusted to Year 2000 level of Development

Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor	Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor[1]
1942	116347	18814	81870	179403	1.54	1972	33025	51429	81870	63466	1.92
1943	22737	19901	81870	84706	3.73	1973	91677	52516	81870	121031	1.32
1944	25684	20988	81870	86566	3.37	1974	41542	53604	81870	69809	1.68
1945	34052	22075	81870	93848	2.76	1975	47851	54691	81870	75031	1.57
1946	23535	23162	81870	82243	3.49	1976	33098	55778	81870	59190	1.79
1947	56240	24250	81870	113861	2.02	1977	22596	56865	81870	47602	2.11
1948	29344	25337	81870	85877	2.93	1978	33078	57952	81870	56996	1.72
1949	41122	26424	81870	96568	2.35	1979	71512	59040	81870	94343	1.32
1950	16365	27511	81870	70724	4.32	1980	79067	60127	81870	100810	1.28
1951	16377	28598	81870	69649	4.25	1981	45277	61214	81870	65933	1.46
1952	22498	29686	81870	74683	3.32	1982	54465	62301	81870	74034	1.36
1953	12341	30773	81870	63439	5.14	1983	136264	63388	81870	154746	1.14
1954	11511	31860	81870	61522	5.34	1984	98608	64475	81870	116003	1.18
1955	12500	32947	81870	61424	4.91	1985	84712	65563	81870	101020	1.19
1956	12387	34034	81870	60223	4.86	1986	65362	66650	81870	80582	1.23
1957	27803	35122	81870	74552	2.68	1987	103200	67737	81870	117333	1.14
1958	26133	36209	81870	71795	2.75	1988	76437	68824	81870	89483	1.17
1959	21884	37296	81870	66458	3.04	1989	69911	69911	81870	81870	1.17
1960	27102	38383	81870	70589	2.60	1990	79965	70999	81870	90837	1.14
1961	33308	39470	81870	75708	2.27	1991	76020	72086	81870	85804	1.13
1962	19538	40557	81870	60851	3.11	1992	72386	73173	81870	81084	1.12
1963	12441	41645	81870	52667	4.23	1993	58414	74260	81870	66025	1.13
1964	10180	42732	81870	49319	4.84	1994	50110	75347	81870	56633	1.13
1965	41078	43819	81870	79129	1.93	1995	90222	76435	81870	95658	1.06
1966	18205	44906	81870	55170	3.03	1996	65159	77522	81870	69508	1.07
1967	27412	45993	81870	63289	2.31	1997	80750	78609	81870	84011	1.04
1968	19083	47081	81870	53873	2.82	1998	93877	79696	81870	96052	1.02
1969	101509	48168	81870	135212	1.33	1999	89735	80783	81870	90822	1.01
1970	85346	49255	81870	117962	1.38	2000	60062	81870	81870	60062	1.00
1971	41741	50342	81870	73269	1.76						

[1] Note – Correction Factor applied to daily flow values for that year to adjust to Year 2000 development

Table H-A-2

Incremental Inflow - Henderson Reach

Inflows adjusted to Year 2000 level of Development

Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor	Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor[1]
1942	114988	36899	181218	259307	2.26	1972	114238	111547	181218	183909	1.61
1943	35427	39387	181218	177258	5.00	1973	220792	114035	181218	287975	1.30
1944	23267	41875	181218	162609	6.99	1974	176374	116523	181218	241069	1.37
1945	46667	44364	181218	183522	3.93	1975	116724	119011	181218	178930	1.53
1946	22793	46852	181218	157159	6.90	1976	91358	121500	181218	151077	1.65
1947	76343	49340	181218	208221	2.73	1977	79243	123988	181218	136473	1.72
1948	72944	51828	181218	202333	2.77	1978	104773	126476	181218	159514	1.52
1949	70116	54317	181218	197017	2.81	1979	120326	128965	181218	172579	1.43
1950	34838	56805	181218	159251	4.57	1980	177536	131453	181218	227302	1.28
1951	63795	59293	181218	185719	2.91	1981	78096	133941	181218	125372	1.61
1952	49538	61781	181218	168975	3.41	1982	100028	136429	181218	144817	1.45
1953	50947	64270	181218	167895	3.30	1983	311661	138918	181218	353962	1.14
1954	17460	66758	181218	131920	7.56	1984	283477	141406	181218	323289	1.14
1955	27886	69246	181218	139857	5.02	1985	149000	143894	181218	186323	1.25
1956	51404	71735	181218	160887	3.13	1986	126330	146382	181218	161165	1.28
1957	137294	74223	181218	244290	1.78	1987	121606	148871	181218	153953	1.27
1958	66511	76711	181218	171018	2.57	1988	124690	151359	181218	154550	1.24
1959	35930	79199	181218	137949	3.84	1989	99240	153847	181218	126611	1.28
1960	54618	81688	181218	154148	2.82	1990	108044	156335	181218	132927	1.23
1961	99907	84176	181218	196949	1.97	1991	122877	158824	181218	145272	1.18
1962	74739	86664	181218	169293	2.27	1992	132089	161312	181218	151995	1.15
1963	28835	89152	181218	120900	4.19	1993	111040	163800	181218	128458	1.16
1964	50374	91641	181218	139951	2.78	1994	79762	166288	181218	94692	1.19
1965	155514	94129	181218	242603	1.56	1995	282189	168777	181218	294631	1.04
1966	53466	96617	181218	138067	2.58	1996	150635	171265	181218	160588	1.07
1967	80177	99105	181218	162290	2.02	1997	233971	173753	181218	241436	1.03
1968	57383	101594	181218	137007	2.39	1998	160570	176241	181218	165546	1.03
1969	106764	104082	181218	183900	1.72	1999	239776	178730	181218	242264	1.01
1970	166331	106570	181218	240979	1.45	2000	129029	181218	181218	129029	1.00
1971	162723	109058	181218	234882	1.44						

[1] Note – Correction Factor applied to daily flow values for that year to adjust to Year 2000 development

Table H-A-3

Incremental Inflow - Kersey Reach

Inflows adjusted to Year 2000 level of Development

Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor	Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor[1]
1942	655554	274647	562330	943237	1.44	1972	235033	423448	562330	373914	1.59
1943	263495	279607	562330	546218	2.07	1973	882132	428408	562330	1016053	1.15
1944	244153	284567	562330	521916	2.14	1974	309271	433368	562330	438232	1.42
1945	228477	289527	562330	501280	2.19	1975	330460	438328	562330	454461	1.38
1946	159121	294487	562330	426963	2.68	1976	227314	443288	562330	346356	1.52
1947	508908	299447	562330	771791	1.52	1977	155091	448248	562330	269172	1.74
1948	227491	304407	562330	485414	2.13	1978	297707	453208	562330	406828	1.37
1949	496339	309367	562330	749302	1.51	1979	763225	458169	562330	867386	1.14
1950	144166	314327	562330	392169	2.72	1980	1162276	463129	562330	1261477	1.09
1951	270864	319287	562330	513907	1.90	1981	220615	468089	562330	314856	1.43
1952	367915	324247	562330	605998	1.65	1982	329291	473049	562330	418572	1.27
1953	163532	329207	562330	396654	2.43	1983	1638253	478009	562330	1722574	1.05
1954	94155	334167	562330	322317	3.42	1984	954249	482969	562330	1033610	1.08
1955	106745	339127	562330	329947	3.09	1985	405818	487929	562330	480219	1.18
1956	106414	344087	562330	324657	3.05	1986	625755	492889	562330	695196	1.11
1957	495679	349047	562330	708961	1.43	1987	412511	497849	562330	476991	1.16
1958	591615	354007	562330	799938	1.35	1988	259812	502809	562330	319332	1.23
1959	303001	358968	562330	506363	1.67	1989	256821	507769	562330	311381	1.21
1960	260227	363928	562330	458629	1.76	1990	337294	512729	562330	386895	1.15
1961	738400	368888	562330	931842	1.26	1991	335332	517689	562330	379973	1.13
1962	385283	373848	562330	573764	1.49	1992	332333	522649	562330	372013	1.12
1963	189294	378808	562330	372816	1.97	1993	335485	527609	562330	370206	1.10
1964	148023	383768	562330	326585	2.21	1994	232476	532569	562330	262236	1.13
1965	519067	388728	562330	692668	1.33	1995	985967	537529	562330	1010767	1.03
1966	145219	393688	562330	313861	2.16	1996	429823	542489	562330	449663	1.05
1967	346641	398648	562330	510322	1.47	1997	855127	547449	562330	870007	1.02
1968	182101	403608	562330	340822	1.87	1998	387860	552410	562330	397780	1.03
1969	594219	408568	562330	747980	1.26	1999	750363	557370	562330	755323	1.01
1970	507299	413528	562330	656100	1.29	2000	238015	562330	562330	238015	1.00
1971	561713	418488	562330	705555	1.26						

[1] Note – Correction Factor applied to daily flow values for that year to adjust to Year 2000 development

Table H-A-4

Incremental Inflow - Julesburg Reach

Inflows adjusted to Year 2000 level of Development

Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor	Year	Annual Volume (ac-ft)	Linear Reg Volume (ac-ft)	Baseline Volume (ac-ft)	Adjusted Volume (ac-ft)	Correction Factor[1]
1942	40445	24214	30382	46613	1.15	1972	3582	27404	30382	6560	1.83
1943	56549	24320	30382	62611	1.11	1973	94771	27510	30382	97642	1.03
1944	5473	24426	30382	11429	2.09	1974	27102	27617	30382	29867	1.10
1945	12225	24533	30382	18074	1.48	1975	12113	27723	30382	14771	1.22
1946	45532	24639	30382	51274	1.13	1976	2652	27829	30382	5204	1.96
1947	12628	24745	30382	18265	1.45	1977	7695	27936	30382	10141	1.32
1948	38555	24852	30382	44085	1.14	1978	0	28042	30382	0	1.00
1949	46592	24958	30382	52016	1.12	1979	8898	28149	30382	11131	1.25
1950	21083	25065	30382	26400	1.25	1980	55364	28255	30382	57491	1.04
1951	9468	25171	30382	14679	1.55	1981	4548	28361	30382	6568	1.44
1952	22688	25277	30382	27792	1.22	1982	7521	28468	30382	9435	1.25
1953	4343	25384	30382	9341	2.15	1983	63837	28574	30382	65645	1.03
1954	1118	25490	30382	6010	5.37	1984	54584	28680	30382	56286	1.03
1955	5636	25596	30382	10421	1.85	1985	43457	28787	30382	45053	1.04
1956	0	25703	30382	0	1.00	1986	29409	28893	30382	30898	1.05
1957	4944	25809	30382	9517	1.92	1987	24444	28999	30382	25826	1.06
1958	57263	25915	30382	61729	1.08	1988	51937	29106	30382	53213	1.02
1959	23845	26022	30382	28205	1.18	1989	4591	29212	30382	5761	1.25
1960	6376	26128	30382	10629	1.67	1990	19509	29318	30382	20572	1.05
1961	5047	26234	30382	9194	1.82	1991	12470	29425	30382	13427	1.08
1962	36325	26341	30382	40366	1.11	1992	31579	29531	30382	32430	1.03
1963	19651	26447	30382	23586	1.20	1993	44884	29637	30382	45629	1.02
1964	421	26553	30382	4250	10.08	1994	7357	29744	30382	7995	1.09
1965	105594	26660	30382	109317	1.04	1995	3056	29850	30382	3588	1.17
1966	44718	26766	30382	48334	1.08	1996	51987	29956	30382	52412	1.01
1967	16450	26872	30382	19959	1.21	1997	25390	30063	30382	25709	1.01
1968	52639	26979	30382	56042	1.06	1998	46754	30169	30382	46967	1.00
1969	7486	27085	30382	10782	1.44	1999	45963	30275	30382	46069	1.00
1970	88842	27191	30382	92032	1.04	2000	19074	30382	30382	19074	1.00
1971	14107	27298	30382	17191	1.22						

[1] Note – Correction Factor applied to daily flow values for that year to adjust to Year 2000 development

Table H-A-5
Annual Average Daily Inflow, Year Used to Develop Water Right Demands, and Estimated Historic Water Right Demands

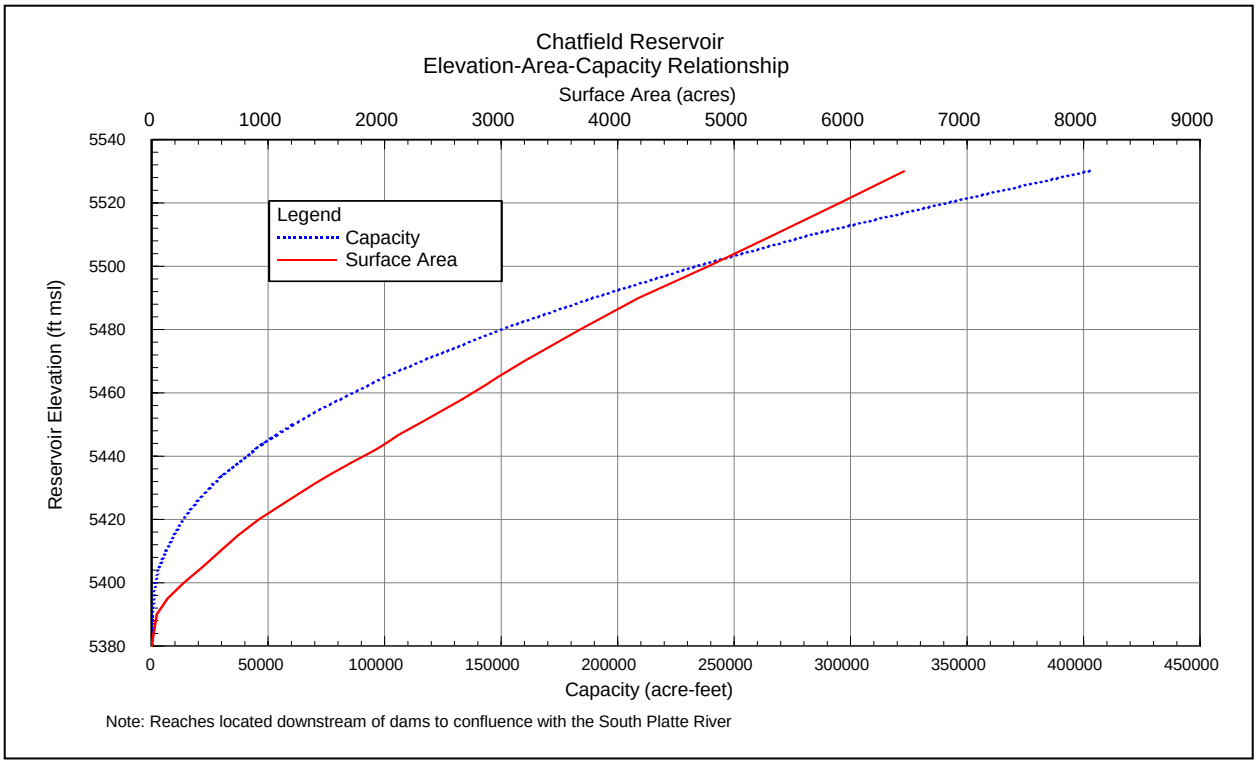
Year	Annual Average Daily Inflow (cfs)	Water Right Demand Year Used (year)	Water Right Demand Average Daily Flow (cfs)	Year	Annual Average Daily Inflow (cfs)	Water Right Demand Year Used (year)	Water Right Demand Average Daily Flow (cfs)
1942	784.4	1983	134.1	**1972**	111.2	1996	95.9
1943	133.3	1989	125.6	**1973**	589.0	1983	134.3
1944	221.0	1979	149.7	**1974**	161.6	1997	101.3
1945	233.2	1979	149.9	**1975**	174.0	1989	126.1
1946	126.7	2000	103.5	**1976**	145.3	------	142.1
1947	429.0	1995	116.2	**1977**	106.8	------	102.3
1948	427.6	1995	115.6	**1978**	93.1	------	91.3
1949	445.5	1995	116.1	**1979**	223.3	------	149.7
1950	87.7	1978	91.7	**1980**	469.4	------	99.0
1951	108.0	1977	102.2	**1981**	81.6	------	60.2
1952	142.6	1976	141.5	**1982**	168.0	------	117.5
1953	116.6	1996	96.1	**1983**	613.8	------	134.1
1954	56.5	1981	60.3	**1984**	683.1	------	362.6
1955	111.4	1996	95.6	**1985**	369.8	------	180.5
1956	73.7	1981	60.3	**1986**	161.5	------	128.5
1957	388.7	1985	181.1	**1987**	373.6	------	128.1
1958	239.7	1998	175.1	**1988**	168.5	------	105.7
1959	133.3	1976	142.9	**1989**	139.2	------	125.6
1960	205.3	1979	149.9	**1990**	111.3	------	94.7
1961	207.4	1979	150.2	**1991**	102.4	------	84.9
1962	196.1	1979	149.3	**1992**	107.9	------	83.6
1963	61.9	1981	60.1	**1993**	97.5	------	90.1
1964	95.9	1993	89.6	**1994**	103.4	------	93.4
1965	344.4	1999	153.3	**1995**	464.6	------	116.3
1966	91.8	1978	91.1	**1996**	113.5	------	95.7
1967	103.3	1994	93.4	**1997**	166.7	------	101.1
1968	137.6	1989	124.9	**1998**	245.7	------	175.1
1969	387.6	1987	127.9	**1999**	334.6	------	153.2
1970	557.0	1983	134.2	**2000**	121.5	------	103.4
1971	174.1	1982	117.0				

APPENDIX H-B

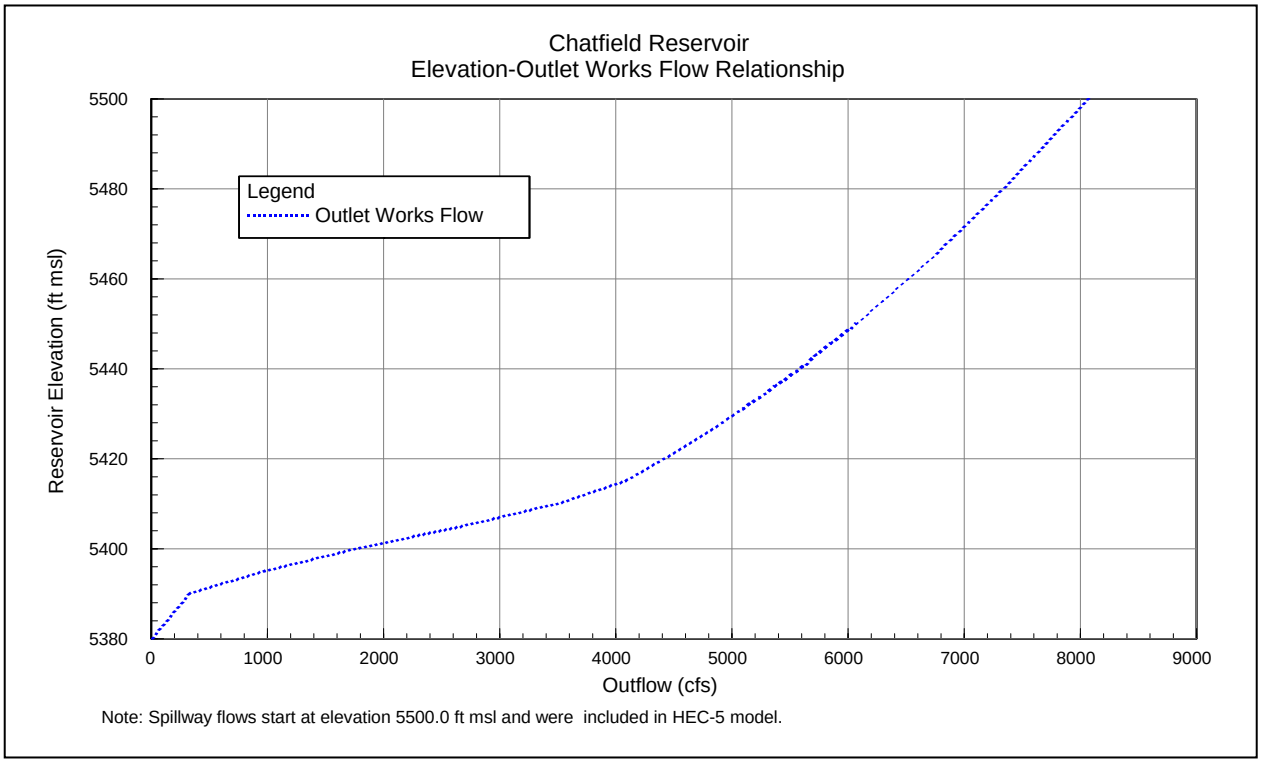
ELEVATION-AREA-CAPACITY-OUTFLOW RELATIONSHIPS
CHATFIELD, BEAR CREEK, AND CHERRY CREEK
RESERVOIRS

STORAGE-OUTFLOW RELATIONSHIPS
THE SOUTH PLATTE RIVER

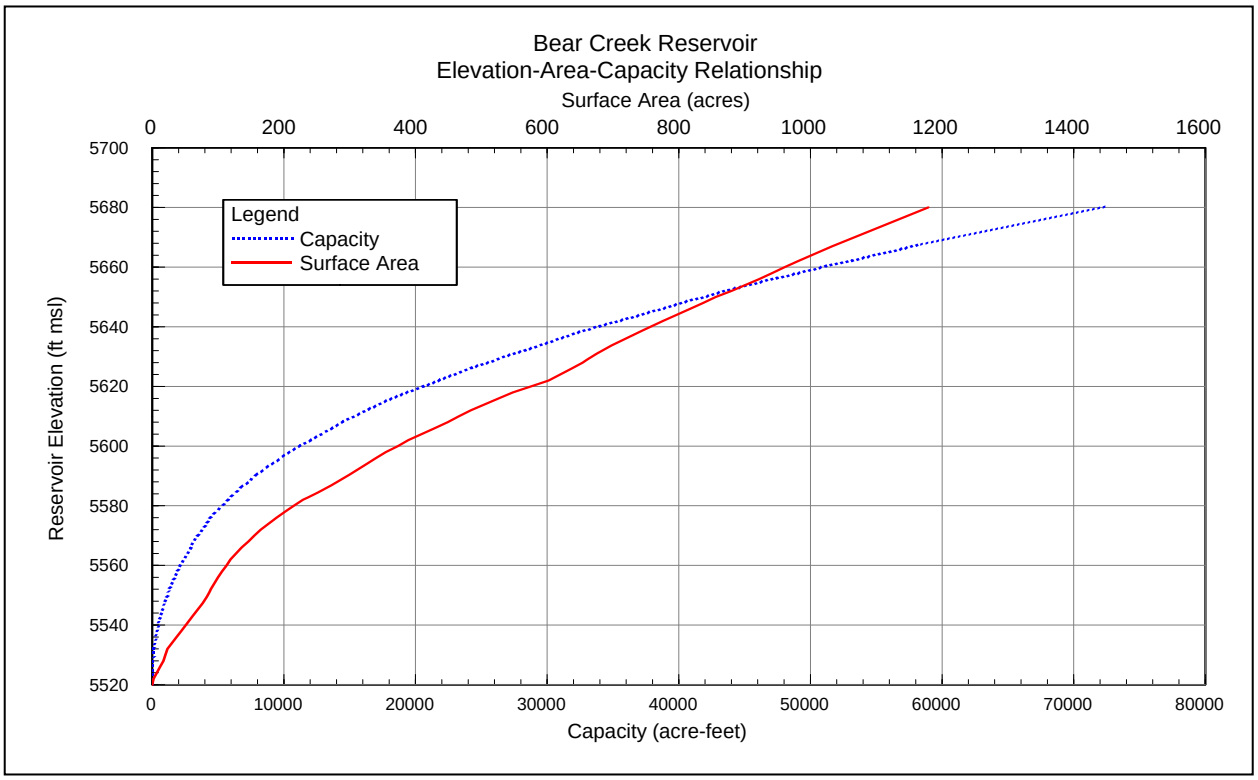
CHATFIELD RESERVOIR
WITH PROJECT CONDITIONS
NEW MONTHLY STORABLE FLOWS AND RELEASES



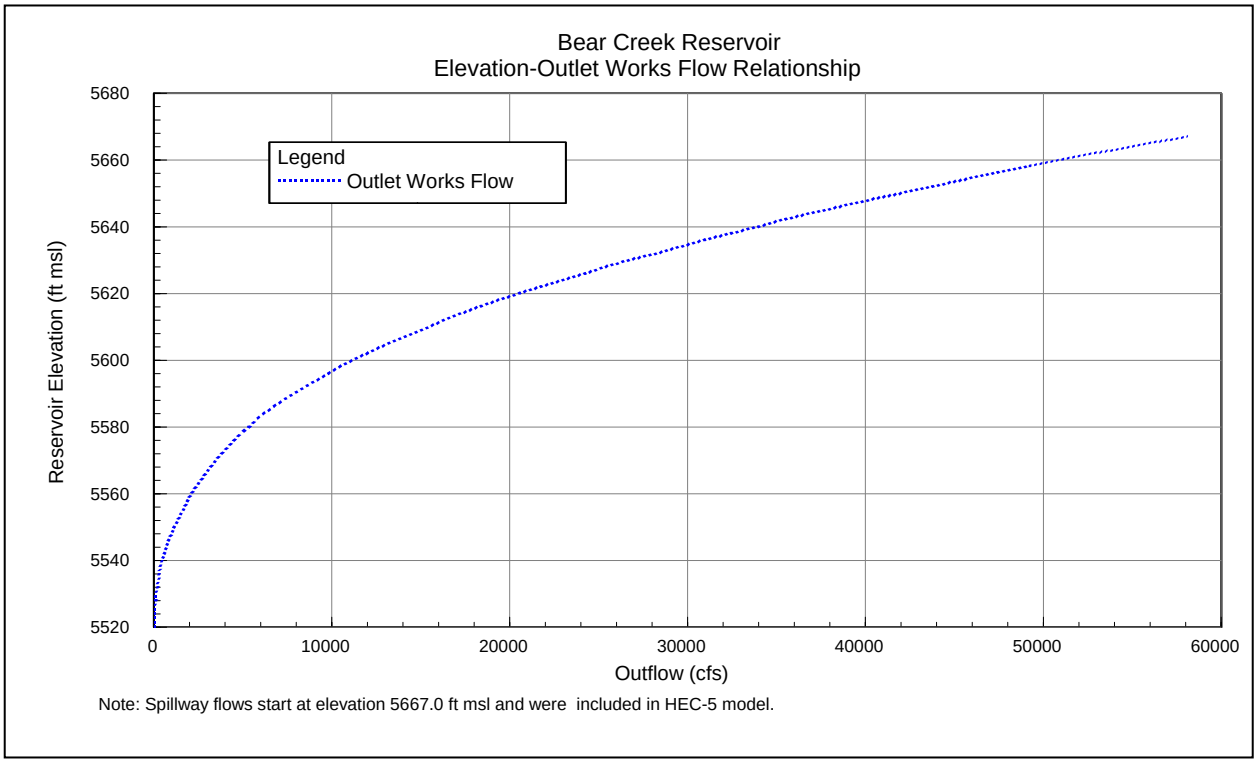
Chatfield Reservoir Elevation-Area-Capacity Relationship



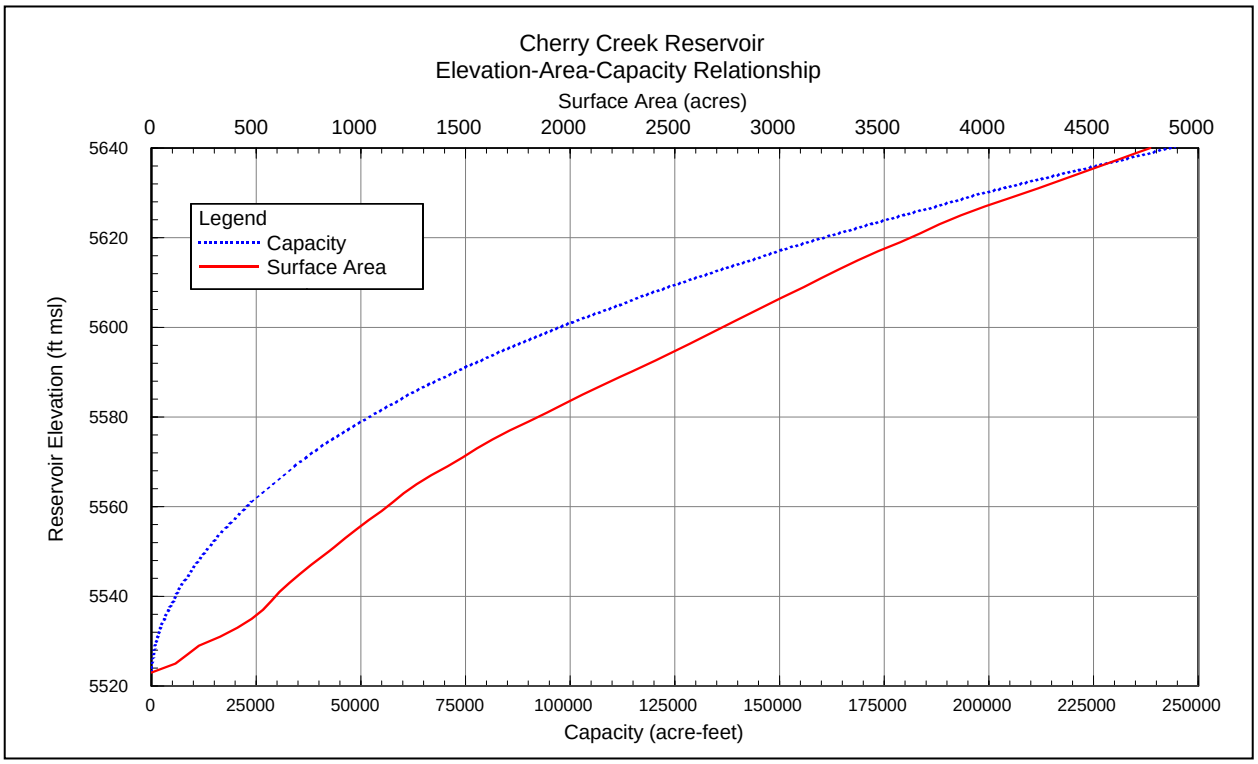
Chatfield Reservoir Elevation-Outwork Works Flow Relationship



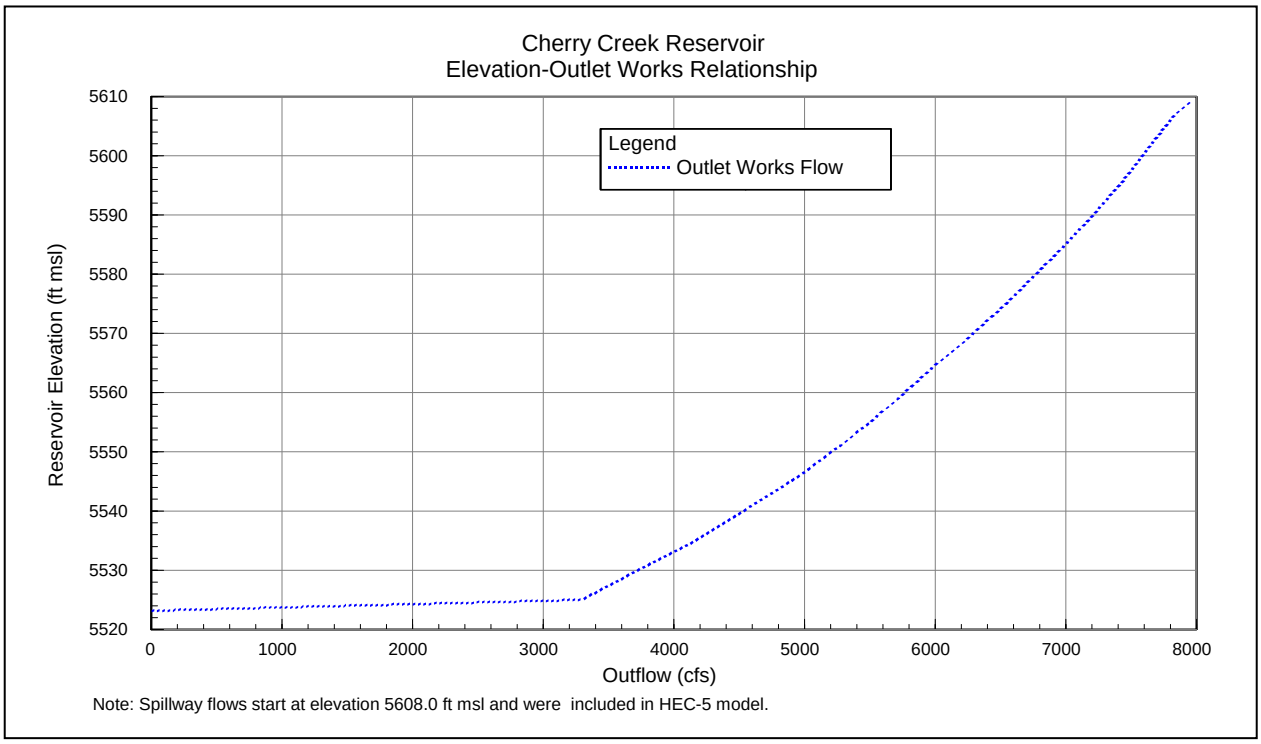
Bear Creek Reservoir Elevation-Area-Capacity Relationship



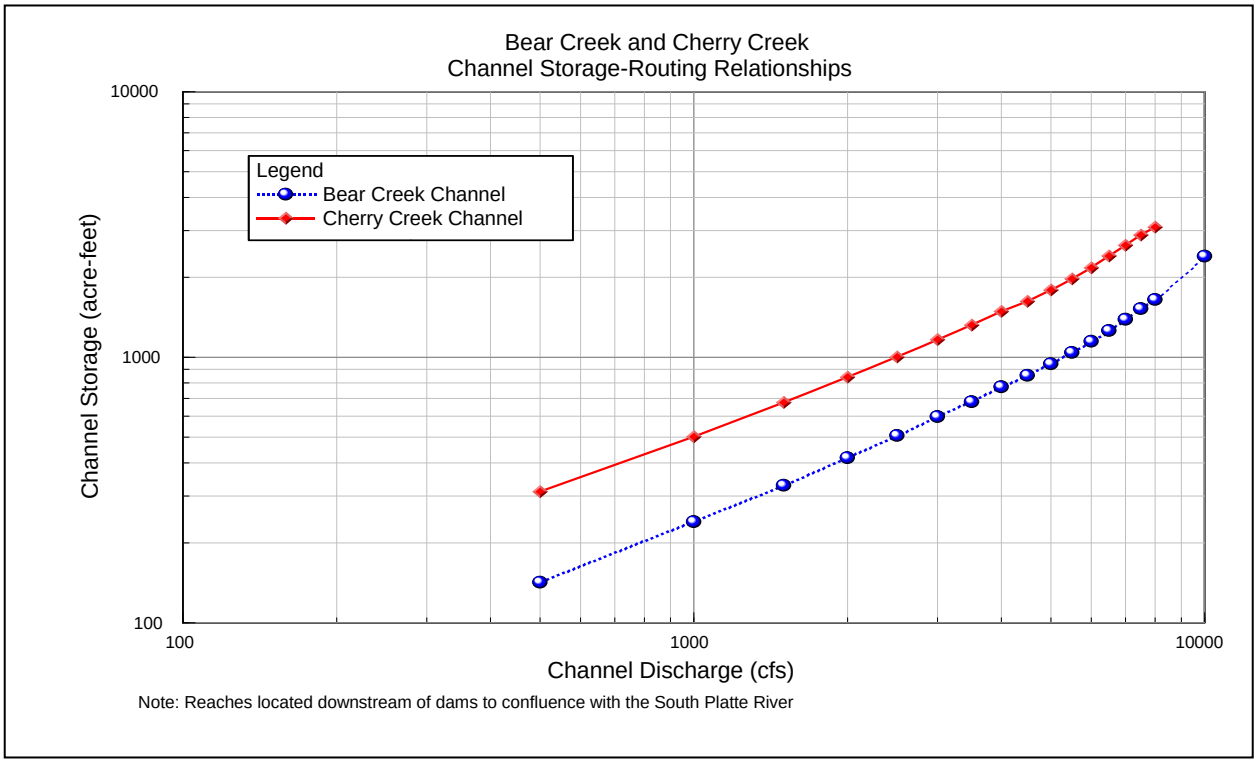
Bear Creek Reservoir Elevation-Outwork Works Flow Relationship



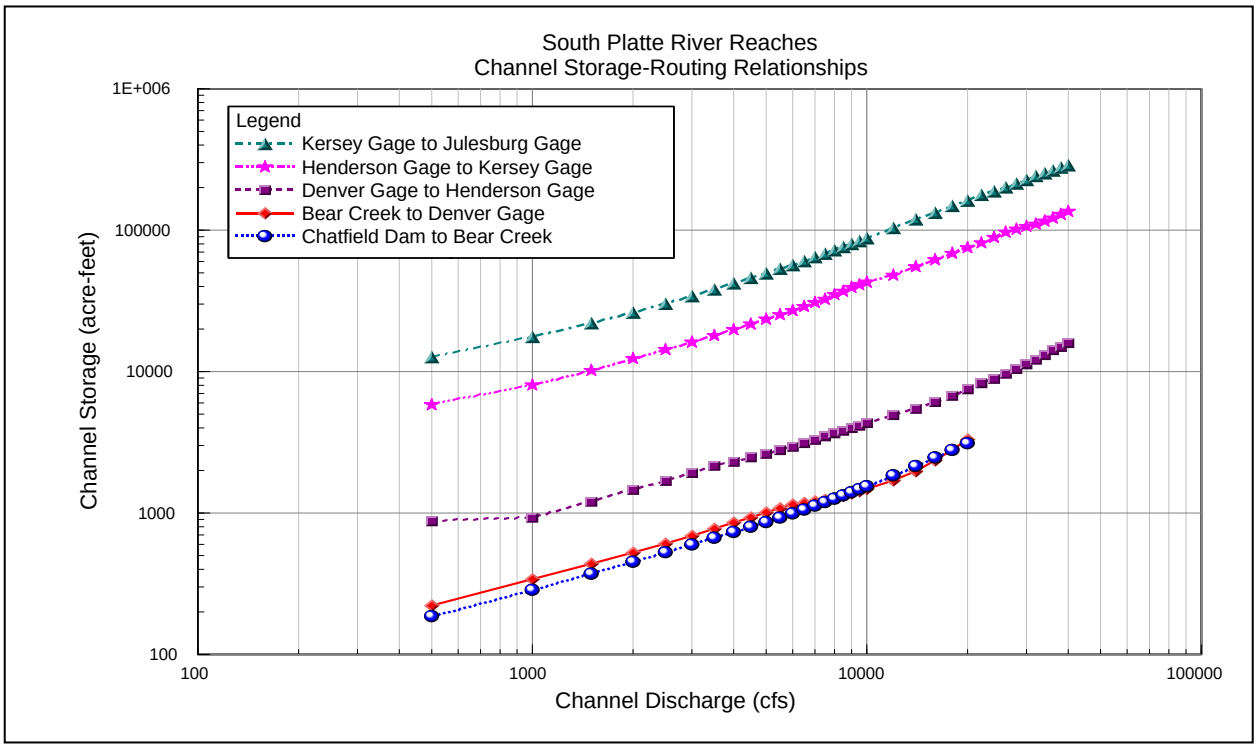
Cherry Creek Reservoir Elevation-Area-Capacity Relationship



Cherry Creek Reservoir Elevation-Outwork Works Flow Relationship



Bear Creek and Cherry Creek Channel Storage-Routing Relationships



South Platte River Reaches Channel Storage-Routing Relationships

Chatfield Reservoir
With Project Conditions (5444.0 ft msl Top of Conservation Pool)
Average Monthly Storable Inflows to Chatfield Reservoir (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1942	0.0	0.0	0.0	179.0	72.7	37.9	38.1	14.3	0.0	0.0	0.0	0.0	28.5
1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.02
1944	0.0	0.0	0.0	0.0	0.6	103.3	0.8	0.0	0.0	2.0	0.0	0.0	8.9
1945	0.0	0.0	0.0	0.0	0.7	104.9	0.9	0.0	0.0	0.0	0.0	0.0	8.9
1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1947	0.0	0.0	0.0	0.0	82.7	207.3	48.8	0.0	0.0	3.2	0.0	0.0	28.5
1948	0.0	0.0	12.8	144.9	120.7	63.7	0.0	0.0	0.0	0.0	0.0	0.0	28.5
1949	0.0	0.0	0.0	0.0	45.6	241.4	55.1	0.0	0.0	0.0	0.0	0.0	28.5
1950	0.0	0.0	0.0	0.0	7.4	8.5	0.0	0.0	0.0	0.0	0.0	0.0	1.3
1951	0.0	0.0	0.0	0.0	0.0	3.9	0.0	16.4	0.0	0.0	0.0	0.0	1.7
1952	0.0	0.0	0.0	0.0	4.1	14.8	0.0	0.0	0.0	0.0	0.0	0.0	1.6
1953	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.18
1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	0.0	0.0	0.0	0.0	23.2	0.0	0.0	2.3	0.0	0.0	0.0	0.0	2.1
1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	0.0	0.0	0.0	0.0	273.9	44.0	20.7	3.5	0.0	0.0	0.0	0.0	28.5
1958	0.0	0.0	0.0	0.0	222.9	42.1	0.0	0.0	0.0	0.0	0.0	0.0	22.1
1959	0.0	0.0	0.0	0.0	10.7	0.0	0.0	0.0	2.6	0.0	0.0	0.0	1.1
1960	0.0	0.0	2.8	0.0	22.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	2.1
1961	0.0	0.0	0.0	0.0	23.4	0.0	0.0	0.0	21.0	0.0	0.0	0.0	3.7
1962	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2
1963	0.0	0.0	0.0	0.0	0.0	15.1	0.0	0.0	0.0	0.0	0.0	0.0	1.3
1964	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
1965	0.0	0.0	0.0	0.0	2.9	261.8	23.8	44.3	9.2	0.0	0.0	0.0	28.5
1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.0	0.0	5.2	4.8	3.9	0.0	0.0	0.0	0.0	0.0	1.2
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.0	0.0	305.5	29.8	6.8	0.0	0.0	0.0	0.0	0.0	28.5
1970	0.0	0.0	0.0	89.7	153.2	48.9	48.7	0.0	1.5	0.0	0.0	0.0	28.5
1971	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	0.0	0.0	26.0	241.9	55.1	17.2	0.0	1.8	0.0	0.0	0.0	28.5
1974	0.0	0.0	8.7	22.5	3.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	3.0
1975	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.03
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.02
1979	0.0	0.0	0.0	0.0	18.7	87.1	0.8	0.0	0.0	0.0	0.0	0.0	8.9
1980	0.0	0.0	0.0	40.2	236.9	47.2	17.8	0.0	0.0	0.0	0.0	0.0	28.5
1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	183.2	55.5	39.5	43.8	20.1	0.0	0.0	0.0	0.0	28.5
1984	0.0	0.0	11.4	135.4	45.2	51.7	19.2	45.2	17.6	5.8	5.3	5.1	28.5
1985	7.8	18.2	38.1	92.3	98.8	62.6	18.2	6.1	0.0	0.0	0.0	0.0	28.5
1986	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.03
1987	0.0	0.0	0.0	190.6	88.2	53.5	9.7	0.0	0.0	0.0	0.0	0.0	28.5
1988	0.0	0.0	0.0	15.7	49.4	0.0	13.4	1.5	0.0	0.0	0.0	0.0	6.7
1989	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.01
1990	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
1991	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.03
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.0	8.1	7.8	0.0	0.0	0.0	0.0	0.0	0.0	1.3
1994	0.0	0.0	0.0	0.0	0.0	4.5	0.0	14.0	0.0	1.8	0.0	0.0	1.7
1995	0.0	0.0	8.0	83.6	191.8	58.5	0.0	0.0	0.0	0.0	0.0	0.0	28.5
1996	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2
1997	0.0	0.0	4.4	10.3	2.4	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
1998	0.0	0.0	0.0	0.0	212.5	52.4	0.0	0.0	0.0	0.0	0.0	0.0	22.1
1999	0.0	0.0	0.0	0.0	256.9	50.2	26.5	8.4	0.0	0.0	0.0	0.0	28.5
2000	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Note: Only includes water available for storage using water rights subject to Colorado's water rights priority system.

Chatfield Reservoir
With Project Conditions (5444.0 ft msl Top of Conservation Pool)
Average Monthly Flows Diverted from Chatfield Reservoir[1] (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1942	0.2	0.2	1.7	1.8	7.0	38.0	36.6	36.6	39.5	34.6	37.4	2.0	19.6
1943	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.4	5.9	1.3	2.1	2.0	3.3
1944	2.0	2.1	1.9	2.0	5.1	4.4	4.3	3.8	22.2	0.4	2.1	2.0	4.3
1945	2.0	2.2	1.9	2.0	4.3	3.6	3.4	3.8	22.2	0.4	2.1	2.0	4.2
1946	2.0	2.2	1.9	2.0	3.5	3.6	3.4	3.8	4.2	0.4	2.1	2.0	2.6
1947	2.0	2.2	1.9	2.0	4.3	3.6	39.6	38.6	41.8	34.6	37.4	2.0	17.5
1948	2.0	2.1	1.9	2.0	18.2	38.0	36.6	5.6	39.5	33.8	37.4	2.0	18.2
1949	2.0	2.2	1.9	25.4	7.6	37.2	39.6	7.7	41.8	34.6	37.4	2.0	19.9
1950	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.4	5.9	1.3	2.1	2.0	3.3
1951	2.0	2.2	1.9	2.0	5.1	4.4	4.3	4.6	5.1	1.3	2.1	2.0	3.1
1952	2.0	2.1	1.9	2.0	13.7	5.2	5.1	5.4	5.9	2.1	2.1	2.0	4.1
1953	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.4	5.9	1.3	2.1	2.0	3.3
1954	2.0	2.2	1.9	2.0	5.1	4.4	4.3	3.8	4.2	0.4	2.0	1.9	2.8
1955	2.0	2.2	1.9	2.0	4.3	3.6	3.4	3.8	4.2	0.4	2.0	1.9	2.6
1956	2.0	2.1	1.9	2.0	4.4	3.6	3.4	3.8	4.2	0.4	2.0	1.9	2.6
1957	2.0	2.2	1.9	2.0	4.3	36.3	35.7	5.6	39.5	34.6	37.4	2.0	17.0
1958	2.0	2.2	1.9	2.0	28.8	5.8	5.7	6.0	40.1	34.6	37.4	2.0	14.0
1959	2.0	2.2	1.9	25.4	14.6	5.8	5.7	6.0	6.5	2.1	2.1	2.0	6.3
1960	2.0	2.1	1.9	2.0	72.2	7.7	5.1	5.4	5.9	2.1	2.1	2.0	9.2
1961	2.0	2.2	1.9	25.3	31.7	7.7	5.1	5.4	5.9	2.1	2.1	2.0	7.8
1962	2.0	2.2	12.1	10.5	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	5.0
1963	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.4
1964	2.0	2.1	1.9	1.1	4.3	4.4	4.3	3.8	4.2	0.4	2.1	2.0	2.7
1965	2.0	2.2	1.9	2.0	4.3	4.3	39.6	17.2	73.7	34.6	37.4	2.0	18.4
1966	2.0	2.2	4.8	2.0	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.7
1967	2.0	2.2	1.9	2.0	5.1	5.2	5.1	4.6	4.2	1.2	2.1	2.0	3.1
1968	2.0	2.1	1.9	1.9	4.3	3.6	3.4	3.8	4.2	0.4	2.1	2.0	2.6
1969	2.0	2.2	1.9	1.9	21.9	50.7	6.2	6.2	40.1	34.6	37.4	11.3	18.0
1970	2.0	2.2	1.9	35.5	17.0	38.6	37.1	37.1	40.1	34.6	37.4	2.0	23.8
1971	2.0	2.2	1.9	15.1	41.9	5.2	5.1	5.4	5.9	2.1	2.1	2.0	7.6
1972	2.0	2.1	1.9	2.0	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.4
1973	2.0	2.2	1.9	36.7	26.0	59.2	38.8	7.2	40.1	34.6	37.4	2.0	24.0
1974	7.7	7.5	25.8	53.3	9.6	5.2	5.1	5.4	5.9	2.1	2.1	2.0	11.0
1975	2.0	2.2	1.9	12.9	6.8	12.6	5.1	5.4	5.9	2.1	2.1	2.0	5.1
1976	2.0	2.1	1.9	2.0	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.4
1977	2.0	2.2	1.9	2.0	5.1	4.9	4.3	4.6	4.2	0.4	2.1	2.0	3.0
1978	2.0	2.2	1.9	1.9	3.5	3.6	3.4	3.8	4.2	0.4	2.0	1.9	2.6
1979	2.0	2.2	1.9	2.0	24.4	5.2	5.1	5.4	24.0	2.1	2.1	2.0	6.5
1980	2.0	2.1	1.9	38.8	19.5	41.2	37.1	6.2	40.1	34.6	37.4	2.0	21.9
1981	2.0	2.2	1.9	2.0	5.1	11.1	5.1	5.4	5.9	2.1	2.1	2.0	3.9
1982	2.0	2.2	1.9	2.0	6.8	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.6
1983	2.0	2.2	14.2	65.2	19.4	54.1	59.7	48.4	40.2	34.6	37.4	2.0	31.6
1984	2.0	2.1	1.9	27.3	50.4	59.7	40.5	11.1	72.8	35.4	38.2	2.8	28.7
1985	2.8	3.1	20.1	25.6	24.4	42.2	37.1	6.4	40.0	34.9	38.2	2.8	23.1
1986	2.0	2.2	9.2	9.4	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	4.6
1987	2.0	2.2	1.9	34.5	24.4	46.3	36.6	5.6	39.5	34.6	39.0	3.6	22.5
1988	3.6	3.9	9.4	31.2	29.8	5.2	5.1	5.4	10.4	2.1	2.1	2.0	9.2
1989	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.4
1990	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.4	5.9	1.9	2.1	2.0	3.4
1991	2.0	2.2	1.9	2.0	5.1	5.2	5.1	5.3	5.1	1.3	2.1	2.0	3.3
1992	2.0	2.1	5.4	2.0	5.1	5.2	5.1	5.4	5.9	2.0	2.1	2.0	3.7
1993	2.0	2.2	1.9	6.8	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.8
1994	2.0	2.2	1.9	8.9	8.3	5.2	5.1	5.4	5.9	2.1	2.1	2.0	4.3
1995	2.0	2.2	1.9	2.0	17.6	57.8	40.9	6.2	40.1	34.6	37.4	2.0	20.4
1996	2.0	2.1	1.9	2.0	5.1	5.2	5.1	5.4	5.9	2.1	2.1	2.0	3.4
1997	2.0	2.2	1.9	2.0	11.8	6.7	5.1	5.4	5.9	2.1	2.9	2.8	4.2
1998	2.8	3.1	12.0	60.0	79.9	8.4	5.7	6.0	40.1	34.6	37.4	2.0	24.3
1999	2.0	2.2	1.9	31.9	21.9	67.0	8.9	9.6	40.1	34.6	37.4	2.0	21.6
2000	2.0	2.1	10.6	7.9	12.2	5.2	5.1	5.4	5.9	2.1	2.1	2.0	5.2

[1] Note: Water users consist of: South Metro Water Supply Authority, Parker Water and Sanitation District, Centennial Water and Sanitation District, Town of Castle Rock, Roxborough Metropolitan District, Castle Pines North Metropolitan District, Castle Pines Metropolitan District, Hock Hocking LLC, Perry Park Country Club, and Center of Colorado Water Conservancy District

Note: Diverted flows include both, Colorado's water rights priority system flows and other inflows not subject to the Colorado water rights priority system, such as non-tributary groundwater.

Chatfield Reservoir
With Project Conditions (5444.0 ft msl Top of Conservation Pool)
Average Monthly Releases Downstream Through Chatfield Reservoir[1] (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1942	0.0	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.5	7.9
1943	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1944	0.1	0.0	0.0	1.0	2.5	15.2	18.5	19.7	19.8	3.2	0.1	0.7	6.7
1945	0.1	0.0	0.0	1.0	2.5	15.2	18.5	19.7	19.8	3.2	0.1	0.7	6.7
1946	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1947	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
1948	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
1949	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
1950	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1951	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	17.8	0.1	0.1	0.7	6.1
1952	0.1	0.0	0.0	0.0	2.4	15.2	1.5	0.2	0.2	0.1	0.1	0.7	1.7
1953	0.1	0.0	0.0	0.0	0.0	2.1	0.1	0.2	0.2	0.1	0.1	0.7	0.3
1954	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.7	0.1
1955	0.1	0.0	0.0	0.0	2.4	15.2	7.1	1.0	0.2	0.1	0.1	0.7	2.2
1956	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.7	0.1
1957	0.1	0.0	0.0	0.0	2.4	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.8
1958	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
1959	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1960	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	1.2	0.1	0.1	0.7	4.7
1961	0.1	0.0	0.0	0.0	2.4	9.5	0.0	0.2	19.1	3.2	0.1	0.7	2.9
1962	0.1	0.0	0.0	1.0	2.5	9.6	0.1	0.2	0.2	0.1	0.1	0.7	1.2
1963	0.1	0.0	0.0	0.0	0.0	14.7	0.6	0.2	0.2	0.1	0.1	0.7	1.4
1964	0.1	0.0	0.0	0.0	2.4	0.4	0.0	0.2	0.2	0.1	0.1	0.7	0.3
1965	0.1	0.0	0.0	0.0	2.4	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.8
1966	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1967	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	1.5	0.1	0.7	6.4
1968	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.7	0.1
1969	0.1	0.0	0.0	0.0	2.4	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.8
1970	0.1	0.0	0.0	1.0	2.5	15.2	18.5	30.3	23.1	3.2	0.1	0.7	7.9
1971	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1972	0.1	0.0	0.0	1.0	2.5	15.2	17.6	0.2	0.2	0.1	0.1	0.7	3.1
1973	0.1	0.0	0.0	0.2	2.4	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.8
1974	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1975	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	17.9	0.1	0.1	0.7	6.1
1976	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.7	0.1
1977	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.7	0.1
1978	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.1	0.7	0.1
1979	0.1	0.0	0.0	0.1	0.2	14.7	18.5	23.8	19.8	3.2	0.1	0.7	6.8
1980	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
1981	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1982	0.1	0.0	0.0	1.0	2.5	15.2	17.3	0.2	0.2	0.1	0.1	0.7	3.1
1983	0.1	0.0	0.0	1.0	2.5	15.2	18.5	30.3	23.1	3.2	0.1	0.7	7.9
1984	0.1	0.0	0.0	1.0	2.5	15.2	18.5	30.3	23.1	3.2	0.1	0.7	7.9
1985	0.1	0.0	0.0	1.0	2.5	15.2	18.5	30.3	23.1	3.2	0.1	0.7	7.9
1986	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1987	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
1988	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1989	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1990	0.1	0.0	0.0	1.0	2.5	15.2	0.4	0.2	0.2	0.1	0.1	0.7	1.7
1991	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.3	0.2	0.1	0.1	0.7	0.1
1992	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.7	0.1
1993	0.1	0.0	0.0	0.0	2.4	13.3	0.3	0.2	0.2	0.1	0.1	0.7	1.4
1994	0.1	0.0	0.0	0.0	0.0	3.0	0.1	16.5	0.7	0.1	0.1	0.7	1.8
1995	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1996	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5
1997	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	0.4	0.1	0.1	0.7	4.6
1998	0.1	0.0	0.0	0.0	2.4	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.8
1999	0.1	0.0	0.0	1.0	2.5	15.2	18.5	27.0	26.5	3.2	0.1	0.7	7.9
2000	0.1	0.0	0.0	1.0	2.5	15.2	18.5	17.3	19.8	3.2	0.1	0.7	6.5

[1] Note: Water users consist of: City of Aurora, City of Brighton, Central Colorado Water Conservancy District, Western Mutual Ditch Company, Colorado Division of Parks and Outdoor Recreation , and Denver Botanic Gardens

Chatfield Reservoir
With Project Conditions (5444.0 ft msl Top of Conservation Pool)
Average Monthly Flows Diverted from South Platte River[1] (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1942	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1943	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1944	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1945	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1946	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1947	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1948	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1949	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1950	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1951	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	17.7	0.0	0.0	0.0	6.0
1952	0.0	0.0	0.0	0.0	2.4	15.2	1.5	0.0	0.0	0.0	0.0	0.0	1.6
1953	0.0	0.0	0.0	0.0	0.0	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2
1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	0.0	0.0	0.0	0.0	2.4	15.2	7.1	0.8	0.1	0.0	0.0	0.0	2.1
1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	0.0	0.0	0.0	0.0	2.4	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1958	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1959	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1960	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	1.0	0.0	0.0	0.0	4.6
1961	0.0	0.0	0.0	0.0	2.4	9.4	0.0	0.0	19.0	3.2	0.0	0.0	2.8
1962	0.0	0.0	0.0	1.0	2.5	9.6	0.1	0.0	0.0	0.0	0.0	0.0	1.1
1963	0.0	0.0	0.0	0.0	0.0	14.7	0.6	0.0	0.0	0.0	0.0	0.0	1.3
1964	0.0	0.0	0.0	0.0	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2
1965	0.0	0.0	0.0	0.0	2.4	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1966	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1967	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	1.4	0.0	0.0	6.3
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.0	0.0	2.4	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1970	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1971	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1972	0.0	0.0	0.0	1.0	2.5	15.2	17.7	0.0	0.0	0.0	0.0	0.0	3.0
1973	0.0	0.0	0.0	0.2	2.4	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1974	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1975	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	17.8	0.0	0.0	0.0	6.0
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
1979	0.0	0.0	0.0	0.2	0.2	14.7	18.5	17.1	19.6	3.2	0.0	0.0	6.1
1980	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1981	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1982	0.0	0.0	0.0	1.0	2.5	15.2	17.3	0.0	0.0	0.0	0.0	0.0	3.0
1983	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1984	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1985	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1986	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1987	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1988	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1989	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1990	0.0	0.0	0.0	1.0	2.5	15.2	0.4	0.0	0.0	0.0	0.0	0.0	1.6
1991	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.0	2.4	13.3	0.3	0.0	0.0	0.0	0.0	0.0	1.3
1994	0.0	0.0	0.0	0.0	0.0	3.0	0.1	16.3	0.6	0.0	0.0	0.0	1.7
1995	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1996	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1997	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	0.3	0.0	0.0	0.0	4.6
1998	0.0	0.0	0.0	0.0	2.4	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
1999	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4
2000	0.0	0.0	0.0	1.0	2.5	15.2	18.5	17.1	19.6	3.2	0.0	0.0	6.4

[1]Note: Water is diverted out of the South Platte River between Hendersen and Kersey gages for the City of Aurora, City of Brighton, Central Colorado Water Conservancy District, and Western Mutual Ditch Company.
Flows are left in-stream and not diverted for Colorado Division of Parks and Outdoor Recreation and Denver Botanic Gardens

APPENDIX H-C

FLOW AND POOL ELEVATION DURATION RELATIONSHIPS

ANNUAL, MONTHLY, AND SEASONAL

CHATFIELD, BEAR CREEK, AND CHERRY CREEK RESERVOIRS AND THE SOUTH PLATTE RIVER

CHATFIELD RESERVOIR ELEVATION DURATION - BASE CONDITIONS (5432.0 FT MSL POOL)

Percent of Time	Reservoir Elevation (ft msl)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	5458.5	5432.0	5432.0	5432.0	5451.6	5458.9	5444.9	5432.0	5438.5	5432.0	5432.0	5432.0	5432.0	5432.0	5458.9	5438.5	5432.0
0.05	5455.7	5432.0	5432.0	5432.0	5451.6	5458.9	5444.9	5432.0	5438.5	5432.0	5432.0	5432.0	5432.0	5432.0	5458.3	5435.1	5432.0
0.1	5452.9	5432.0	5432.0	5432.0	5450.4	5458.7	5444.7	5432.0	5435.4	5432.0	5432.0	5432.0	5432.0	5432.0	5457.2	5433.4	5432.0
0.2	5447.9	5432.0	5432.0	5432.0	5448.6	5457.9	5444.1	5432.0	5434.3	5432.0	5432.0	5432.0	5432.0	5432.0	5455.7	5432.1	5432.0
0.5	5434.1	5432.0	5432.0	5432.0	5437.1	5456.1	5442.6	5432.0	5432.1	5432.0	5432.0	5432.0	5432.0	5432.0	5451.3	5432.1	5432.0
1	5432.1	5432.0	5432.0	5432.0	5432.1	5453.8	5438.1	5432.0	5432.1	5432.0	5432.0	5432.0	5432.0	5432.0	5444.5	5432.1	5432.0
2	5432.1	5432.0	5432.0	5432.0	5432.1	5448.5	5432.1	5432.0	5432.1	5432.0	5432.0	5432.0	5432.0	5432.0	5432.9	5432.1	5432.0
5	5432.1	5432.0	5432.0	5432.0	5432.1	5432.1	5432.1	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.1	5432.0	5432.0
10	5432.0	5432.0	5432.0	5432.0	5432.0	5432.1	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.1	5432.0	5432.0
15	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0
20	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5432.0	5431.9	5431.9	5431.9	5432.0	5432.0	5432.0	5432.0	5432.0	5431.9	5432.0
30	5432.0	5431.9	5432.0	5432.0	5432.0	5432.0	5432.0	5431.2	5431.5	5431.3	5431.7	5431.9	5431.8	5432.0	5432.0	5431.4	5431.8
40	5431.5	5431.6	5432.0	5432.0	5432.0	5431.9	5431.9	5430.5	5430.7	5430.2	5430.2	5430.6	5430.4	5431.9	5431.9	5430.5	5430.4
50	5430.5	5430.5	5431.8	5431.9	5431.8	5431.2	5431.4	5429.9	5429.9	5429.1	5429.2	5429.5	5429.7	5431.5	5431.5	5429.7	5429.5
60	5429.6	5429.7	5430.0	5430.5	5430.8	5430.6	5430.8	5429.0	5429.1	5427.9	5428.1	5428.4	5428.9	5430.0	5430.7	5428.6	5428.5
70	5428.4	5428.5	5429.1	5429.5	5430.0	5430.0	5430.2	5427.9	5427.8	5427.2	5427.4	5426.6	5427.6	5429.1	5430.1	5427.6	5427.2
80	5427.0	5426.4	5427.6	5428.5	5428.6	5428.5	5429.2	5426.9	5427.0	5426.4	5425.8	5425.4	5425.3	5427.4	5428.8	5426.8	5425.6
85	5426.3	5424.9	5425.1	5426.2	5427.2	5427.8	5428.7	5426.4	5426.4	5426.0	5424.9	5424.8	5424.5	5425.2	5428.0	5426.4	5424.7
90	5425.3	5424.0	5424.4	5424.7	5425.8	5427.3	5427.8	5426.4	5426.3	5425.4	5424.0	5423.8	5423.9	5424.4	5427.2	5426.3	5423.9
95	5424.0	5423.8	5424.0	5424.1	5424.2	5426.3	5426.9	5426.3	5426.3	5424.9	5423.3	5423.2	5423.0	5423.9	5426.1	5426.0	5423.2
98	5423.3	5423.6	5423.8	5423.8	5423.6	5425.8	5426.4	5426.2	5426.2	5424.4	5423.0	5423.0	5423.0	5423.7	5424.2	5425.0	5423.0
99	5423.0	5423.5	5423.7	5423.7	5423.4	5424.4	5426.4	5426.2	5426.2	5424.2	5423.0	5423.0	5423.0	5423.6	5423.8	5424.6	5423.0
99.5	5423.0	5423.5	5423.7	5423.6	5423.2	5424.0	5426.4	5426.2	5426.1	5424.1	5423.0	5423.0	5423.0	5423.5	5423.5	5424.4	5423.0
99.8	5423.0	5423.4	5423.6	5423.5	5423.1	5423.9	5426.3	5426.2	5426.1	5423.9	5422.9	5422.9	5423.0	5423.4	5423.3	5424.1	5422.9
99.9	5423.0	5423.3	5423.5	5423.4	5423.0	5423.8	5426.3	5426.2	5426.1	5423.9	5422.9	5422.9	5423.0	5423.4	5423.1	5424.0	5422.9
99.95	5422.9	5423.3	5423.5	5423.4	5423.0	5423.8	5426.3	5426.2	5426.1	5423.8	5422.9	5422.9	5423.0	5423.3	5423.0	5423.9	5422.9
99.99	5422.9	5423.2	5423.4	5423.2	5423.0	5423.7	5426.3	5426.2	5426.1	5423.7	5422.9	5422.9	5423.0	5423.2	5423.0	5423.8	5422.9

Note: Based on daily values. Period of Record 1942 through 2000

CHATFIELD RESERVOIR ELEVATION DURATION - WITH PROJECT CONDITIONS (5437.0 FT MSL POOL)

Percent of Time	Reservoir Elevation (ft msl)																
Equalled or Exceeded	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
0.01	5458.4	5437.0	5437.0	5437.0	5455.0	5460.1	5454.1	5437.0	5440.3	5437.0	5437.0	5437.0	5437.0	5437.0	5460.1	5440.3	5437.0
0.05	5456.0	5437.0	5437.0	5437.0	5455.0	5460.1	5454.1	5437.0	5440.3	5437.0	5437.0	5437.0	5437.0	5437.0	5458.0	5437.1	5437.0
0.1	5454.3	5437.0	5437.0	5437.0	5454.5	5458.7	5453.6	5437.0	5437.6	5437.0	5437.0	5437.0	5437.0	5437.0	5457.1	5437.1	5437.0
0.2	5451.3	5437.0	5437.0	5437.0	5452.4	5457.7	5451.7	5437.0	5437.1	5437.0	5437.0	5437.0	5437.0	5437.0	5456.0	5437.1	5437.0
0.5	5437.6	5437.0	5437.0	5437.0	5444.0	5456.4	5448.5	5437.0	5437.1	5437.0	5437.0	5437.0	5437.0	5437.0	5453.5	5437.1	5437.0
1	5437.1	5437.0	5437.0	5437.0	5437.1	5454.8	5443.9	5437.0	5437.1	5437.0	5437.0	5437.0	5437.0	5437.0	5449.9	5437.1	5437.0
2	5437.1	5437.0	5437.0	5437.0	5437.1	5451.0	5437.1	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.5	5437.0	5437.0
5	5437.0	5437.0	5437.0	5437.0	5437.1	5437.1	5437.1	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.1	5437.0	5437.0
10	5437.0	5437.0	5437.0	5437.0	5437.0	5437.1	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.1	5437.0	5437.0
15	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5436.9	5436.8	5436.9	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0
20	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5437.0	5436.8	5436.6	5436.4	5436.3	5436.9	5437.0	5437.0	5437.0	5436.6	5436.8
30	5436.7	5436.7	5437.0	5437.0	5437.0	5437.0	5437.0	5436.1	5435.7	5435.4	5435.4	5435.7	5436.2	5437.0	5437.0	5435.7	5435.8
40	5435.8	5435.4	5436.5	5436.9	5436.9	5436.7	5436.8	5435.3	5434.8	5434.2	5434.3	5434.6	5435.0	5436.6	5436.8	5434.8	5434.5
50	5434.6	5434.3	5435.5	5436.4	5436.6	5435.9	5436.3	5434.2	5433.9	5432.8	5433.2	5433.6	5433.7	5435.4	5436.2	5433.7	5433.5
60	5433.5	5433.3	5434.2	5434.9	5435.2	5435.0	5435.5	5433.3	5432.9	5432.1	5432.1	5432.3	5432.4	5434.0	5435.2	5432.8	5432.3
70	5432.1	5431.9	5432.3	5432.8	5433.5	5433.8	5434.2	5432.5	5432.2	5431.3	5431.0	5430.3	5430.9	5432.2	5433.9	5431.9	5430.7
80	5429.7	5426.4	5427.9	5428.7	5430.5	5432.9	5432.9	5429.9	5430.7	5429.7	5428.4	5427.2	5426.4	5428.2	5432.2	5430.0	5427.6
85	5427.1	5425.4	5425.9	5426.4	5427.2	5431.1	5431.4	5427.7	5429.1	5427.4	5426.0	5424.9	5424.7	5425.9	5430.6	5428.0	5425.3
90	5426.0	5424.1	5424.4	5424.8	5426.0	5427.6	5430.1	5426.5	5426.7	5426.1	5424.2	5424.0	5424.0	5424.5	5427.7	5426.4	5424.0
95	5424.1	5423.8	5423.9	5424.0	5424.6	5426.4	5428.1	5426.4	5426.4	5425.0	5423.8	5423.8	5423.8	5423.9	5426.2	5426.2	5423.8
98	5423.7	5423.6	5423.8	5423.8	5423.8	5425.8	5426.5	5426.4	5426.4	5424.2	5423.6	5423.6	5423.6	5423.7	5424.6	5425.3	5423.6
99	5423.6	5423.5	5423.7	5423.6	5423.7	5424.4	5426.4	5426.3	5426.3	5424.0	5423.4	5423.5	5423.5	5423.6	5423.9	5424.5	5423.4
99.5	5423.4	5423.4	5423.6	5423.5	5423.5	5423.9	5426.4	5426.3	5426.3	5423.8	5423.3	5423.4	5423.4	5423.5	5423.7	5424.1	5423.3
99.8	5423.3	5423.3	5423.5	5423.4	5423.4	5423.8	5426.3	5426.3	5426.3	5423.7	5423.2	5423.2	5423.3	5423.3	5423.5	5423.9	5423.2
99.9	5423.2	5423.2	5423.5	5423.3	5423.3	5423.7	5426.3	5426.3	5426.2	5423.6	5423.1	5423.2	5423.2	5423.3	5423.4	5423.7	5423.1
99.95	5423.1	5423.2	5423.5	5423.2	5423.2	5423.6	5426.3	5426.3	5426.2	5423.5	5423.1	5423.1	5423.2	5423.2	5423.3	5423.6	5423.1
99.99	5423.0	5423.1	5423.4	5423.1	5423.1	5423.5	5426.3	5426.2	5426.2	5423.4	5422.9	5423.0	5423.1	5423.1	5423.2	5423.4	5423.0

Note: Based on daily values. Period of Record 1942 through 2000

CHATFIELD RESERVOIR ELEVATION DURATION - WITH PROJECT CONDITIONS (5444.0 FT MSL POOL)

Percent of Time Equalled or Exceeded	Reservoir Elevation (ft msl)																
	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
0.01	5465.3	5444.0	5444.0	5444.0	5459.9	5465.7	5458.7	5444.0	5444.3	5444.0	5444.0	5444.0	5444.0	5444.0	5465.7	5444.3	5444.0
0.05	5461.8	5444.0	5444.0	5444.0	5459.9	5465.7	5458.7	5444.0	5444.3	5444.0	5444.0	5444.0	5444.0	5444.0	5465.1	5444.1	5444.0
0.1	5459.4	5444.0	5444.0	5444.0	5459.3	5465.5	5458.4	5444.0	5444.1	5444.0	5444.0	5444.0	5444.0	5444.0	5463.9	5444.1	5444.0
0.2	5456.5	5444.0	5444.0	5444.0	5457.4	5464.7	5457.2	5444.0	5444.1	5444.0	5444.0	5444.0	5444.0	5444.0	5461.8	5444.1	5444.0
0.5	5444.6	5444.0	5444.0	5444.0	5449.0	5462.5	5454.7	5444.0	5444.1	5444.0	5444.0	5444.0	5444.0	5444.0	5458.6	5444.1	5444.0
1	5444.1	5444.0	5444.0	5444.0	5444.1	5459.9	5450.1	5444.0	5444.1	5444.0	5444.0	5444.0	5444.0	5444.0	5455.2	5444.0	5444.0
2	5444.1	5444.0	5444.0	5444.0	5444.1	5456.0	5444.1	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5444.6	5444.0	5444.0
5	5444.0	5444.0	5444.0	5444.0	5444.1	5444.1	5444.1	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5444.1	5444.0	5444.0
10	5444.0	5444.0	5444.0	5444.0	5444.0	5444.1	5444.0	5444.0	5444.0	5443.8	5443.9	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0
15	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5444.0	5443.7	5443.1	5443.0	5443.9	5443.9	5444.0	5444.0	5443.7	5443.8
20	5443.8	5443.9	5444.0	5444.0	5444.0	5444.0	5444.0	5443.7	5443.3	5442.1	5441.8	5442.5	5443.3	5444.0	5444.0	5443.2	5442.5
30	5442.7	5442.4	5442.9	5443.4	5443.7	5443.8	5444.0	5442.7	5442.2	5440.9	5440.7	5440.7	5440.8	5443.0	5443.8	5442.0	5440.7
40	5441.2	5440.5	5441.2	5442.2	5442.9	5442.9	5443.4	5441.7	5441.0	5439.2	5439.1	5439.2	5439.6	5441.3	5443.1	5440.8	5439.3
50	5439.9	5439.0	5440.2	5441.0	5442.1	5441.6	5442.6	5440.7	5439.8	5438.4	5437.8	5438.0	5438.1	5440.2	5442.2	5439.5	5438.0
60	5438.3	5437.0	5438.1	5439.2	5439.8	5440.7	5441.4	5439.7	5438.7	5437.6	5437.0	5436.5	5436.7	5438.0	5440.9	5438.4	5436.8
70	5436.5	5435.1	5436.5	5436.5	5437.2	5439.2	5440.3	5438.1	5436.9	5436.2	5435.3	5434.9	5434.6	5436.0	5439.0	5437.0	5434.9
80	5432.9	5429.4	5429.7	5429.2	5434.0	5435.6	5438.5	5435.4	5433.6	5433.2	5431.4	5430.5	5428.9	5429.4	5435.5	5433.8	5430.6
85	5429.1	5427.7	5427.9	5428.3	5428.0	5431.7	5431.9	5431.7	5432.1	5430.8	5428.4	5427.5	5427.5	5428.0	5430.7	5431.5	5427.7
90	5427.3	5425.4	5426.3	5427.0	5426.7	5428.6	5429.5	5427.1	5430.2	5428.9	5426.9	5426.6	5426.0	5426.3	5428.1	5429.1	5426.6
95	5425.5	5424.7	5424.7	5424.7	5425.3	5426.7	5428.0	5426.8	5427.5	5426.6	5425.0	5424.7	5424.7	5424.7	5426.6	5426.7	5424.8
98	5424.6	5424.3	5424.4	5424.3	5424.7	5426.2	5426.9	5426.7	5426.8	5425.0	5424.5	5424.2	5424.3	5424.3	5425.5	5426.3	5424.3
99	5424.3	5424.1	5424.2	5424.1	5424.5	5425.8	5426.8	5426.6	5426.7	5424.6	5424.2	5424.0	5424.1	5424.1	5424.9	5425.8	5424.1
99.5	5424.0	5423.9	5424.0	5423.9	5424.2	5425.1	5426.7	5426.5	5426.6	5424.4	5424.0	5423.8	5423.9	5423.9	5424.6	5424.8	5423.9
99.8	5423.8	5423.7	5423.9	5423.7	5424.0	5424.8	5426.6	5426.4	5426.5	5424.1	5423.8	5423.6	5423.7	5423.7	5424.2	5424.4	5423.7
99.9	5423.6	5423.6	5423.8	5423.6	5423.8	5424.7	5426.5	5426.4	5426.4	5423.9	5423.6	5423.5	5423.6	5423.6	5424.0	5424.2	5423.5
99.95	5423.5	5423.5	5423.7	5423.5	5423.7	5424.6	5426.5	5426.3	5426.4	5423.7	5423.5	5423.4	5423.5	5423.5	5423.9	5424.0	5423.4
99.99	5423.2	5423.3	5423.5	5423.3	5423.4	5424.4	5426.4	5426.3	5426.2	5423.4	5423.2	5423.2	5423.3	5423.3	5423.5	5423.6	5423.2

Note: Based on daily values. Period of Record 1942 through 2000

CHATFIELD RESERVOIR OUTFLOW DURATION - BASE CONDITIONS (5432.0 FT MSL POOL)

Percent of Time	Reservoir Outflow (cfs)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	5000	303	438	901	5000	5000	5000	3385	5000	1543	1326	1003	436	901	5000	5000	1326
0.05	5000	303	438	901	5000	5000	5000	3385	5000	1543	1326	1003	436	628	5000	3349	1198
0.1	5000	264	340	714	5000	5000	5000	3246	3573	1532	1169	1003	323	516	5000	3052	1044
0.2	4496	213	309	564	5000	5000	5000	2820	2879	1455	971	1001	304	425	5000	2616	949
0.5	2799	173	228	423	3545	5000	4971	2247	2389	912	865	903	283	326	5000	2079	776
1	2259	160	188	348	2327	4996	3557	1993	1533	590	747	605	255	252	3772	1626	527
2	1741	135	138	279	1733	3387	2619	1608	1129	487	408	424	221	196	2729	1264	342
5	958	101	114	191	849	2441	2024	1190	792	346	275	279	173	134	2027	846	242
10	508	86	94	139	507	1874	1601	848	624	253	191	174	130	107	1448	609	162
15	354	76	80	116	391	1428	1311	687	531	205	131	135	104	89	1021	501	124
20	271	69	73	103	309	1091	1047	575	473	176	100	119	88	79	705	423	102
30	175	58	61	79	214	467	619	446	352	127	76	87	70	66	387	300	78
40	117	46	54	68	161	333	385	353	263	90	64	73	57	57	287	224	64
50	83	35	48	57	122	255	299	282	207	73	56	59	40	49	221	174	53
60	64	25	42	52	98	202	244	226	167	65	49	46	26	41	169	135	44
70	51	15	34	45	69	154	191	178	136	58	44	28	14	32	121	95	32
80	37	7	11	35	51	108	140	137	103	51	39	21	11	11	85	69	21
85	25	5.3	5	15	42	91	105	114	87	47	35	15	9.2	7	64	61	14
90	11	3.6	2.5	5.8	17	71	79	93	71	42	30	11	5.5	3.3	47	52	11
95	2.4	1.0	0.9	0.8	0.8	36	24	68	47	36	24	5.8	2.6	0.9	1	41	4.9
98	0.8	0.7	0.7	0.7	0.7	1	0.8	18	1.0	23	12.5	1.0	1.0	0.7	0.7	15	1.1
99	0.7	0.6	0.6	0.6	0.6	0.7	0.6	0.8	0.8	0.9	0.9	0.8	0.8	0.6	0.6	0.8	0.8
99.5	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.7	0.7	0.7	0.8	0.7	0.7	0.5	0.5	0.7	0.7
99.8	0.5	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.5	0.6	0.6	0.5	0.5	0.4	0.4	0.5	0.5
99.9	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.3	0.4	0.4	0.5
99.95	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.4
99.99	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.3

Note: Based on daily values. Period of Record 1942 through 2000

CHATFIELD RESERVOIR OUTFLOW DURATION - WITH PROJECT CONDITIONS (5437.0 FT MSL POOL)

Percent of Time Equalled or Exceeded	Reservoir Outflow (cfs)																
	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
0.01	5000	303	437	609	5000	5000	5000	3368	4986	1541	1312	1003	436	609	5000	4986	1312
0.05	5000	303	437	609	5000	5000	5000	3368	4986	1541	1312	1003	436	510	5000	3171	1196
0.1	5000	243	340	524	5000	5000	5000	3236	3044	1530	1172	1003	323	453	5000	2964	1047
0.2	4289	191	309	436	5000	5000	5000	2822	2774	1456	956	1001	304	395	5000	2561	930
0.5	2849	172	228	399	3151	5000	5000	2236	2113	912	833	878	283	315	5000	1997	758
1	2240	154	188	333	2339	4907	3621	1965	1587	588	731	588	253	241	3739	1616	507
2	1721	133	136	268	1739	3513	2606	1592	1113	469	404	421	221	190	2779	1269	332
5	942	101	111	184	832	2435	2004	1188	774	326	270	274	172	131	2016	844	234
10	505	84	83	133	491	1860	1584	858	614	238	181	164	125	103	1429	616	157
15	349	74	74	113	369	1418	1278	705	523	198	122	129	102	85	1004	509	117
20	266	65	66	99	295	1081	1026	598	466	162	98	109	87	75	681	429	98
30	170	56	56	76	203	440	607	468	345	112	72	81	70	61	373	302	74
40	113	43	48	64	154	317	383	367	257	89	62	64	55	53	278	226	61
50	80	33	42	56	118	245	298	292	207	76	55	52	39	45	211	173	51
60	62	22	33	49	95	188	242	234	167	68	49	34	26	35	161	135	41
70	48	11	11	42	64	142	189	186	140	62	44	23	15	20	116	96	29
80	32	6.3	3.5	27.7	49	100	136	144	106	55	38	16	10	7.0	80	72	20
85	20	4.6	2.2	8.0	38	81	104	120	90	51	34	12	8.4	3.9	59	64	13
90	8.7	3.2	1.0	1.0	7.2	59	77	94	75	45	28	7.8	4.2	1.1	43	56	9.2
95	1.5	0.9	0.8	0.8	0.8	20	8	65	55	38	23	3.5	2.0	0.8	4.2	43	3.3
98	0.8	0.7	0.6	0.6	0.6	0.8	5.7	12	10	10	4.3	0.8	0.9	0.6	0.8	11	0.9
99	0.7	0.6	0.5	0.5	0.5	0.7	4.2	7	8	8	0.9	0.7	0.8	0.5	0.6	8	0.7
99.5	0.6	0.5	0.4	0.5	0.5	0.5	0.8	6.1	6	8	0.8	0.6	0.7	0.5	0.5	6	0.6
99.8	0.4	0.4	0.4	0.4	0.4	0.4	0.6	1.0	1.0	7.8	0.6	0.5	0.6	0.4	0.4	4.9	0.5
99.9	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.8	0.8	7.7	0.5	0.4	0.6	0.3	0.4	0.9	0.4
99.95	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.6	7.7	0.4	0.3	0.5	0.3	0.3	0.7	0.4
99.99	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.4	7.6	0.3	0.2	0.4	0.2	0.2	0.4	0.3

Note: Based on daily values. Period of Record 1942 through 2000

CHATFIELD RESERVOIR OUTFLOW DURATION - WITH PROJECT CONDITIONS (5444.0 FT MSL POOL)

Percent of Time	Reservoir Outflow (cfs)																
Equalled or Exceeded	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
0.01	5000	303	436	608	5000	5000	5000	3340	3027	1555	1289	1003	437	608	5000	3340	1289
0.05	5000	303	436	608	5000	5000	5000	3340	3027	1555	1289	1003	437	510	5000	3134	1168
0.1	5000	243	340	524	5000	5000	5000	3220	2806	1516	1035	1003	323	448	5000	2877	1019
0.2	4734	191	309	435	5000	5000	5000	2824	2673	1347	881	1001	303	385	5000	2507	889
0.5	2763	170	228	390	3151	5000	5000	2237	1898	963	824	858	279	308	5000	1954	764
1	2208	152	188	327	2339	5000	3385	1965	1524	586	734	562	252	241	3772	1584	497
2	1700	131	133	263	1745	3474	2512	1582	1017	438	371	387	219	184	2693	1234	320
5	910	99	109	176	791	2393	1976	1164	765	303	227	272	170	128	1999	829	211
10	488	83	81	128	447	1848	1558	844	615	231	138	157	125	99	1404	618	139
15	342	73	70	106	352	1387	1229	703	521	190	108	124	99	81	969	506	110
20	262	62	64	91	281	1033	1003	596	463	160	91	105	84	72	617	430	93
30	165	51	53	71	191	415	560	473	347	114	73	81	65	57	356	306	73
40	109	36	44	57	143	293	366	382	272	95	63	65	47	48	264	233	60
50	79	27	37	51	109	227	291	303	219	85	56	50	31	39	197	177	50
60	60	18	21	43	74	171	235	244	176	77	50	30	20	25	150	140	39
70	44	9.9	6.8	17	53	127	182	190	151	69	45	21	12	10.2	107	100	26
80	23	5.0	2.2	1.0	6.0	91	121	146	117	62	38	12	8.5	3.3	64	80	14
85	11.6	3.5	1.0	0.9	1.0	72	101	120	99	56	34	9.2	5.1	1.0	47	70	10.7
90	4.4	2.1	0.8	0.8	0.9	44	71	92	83	46	28	5.3	2.5	0.9	13.2	61	6.4
95	0.9	0.8	0.7	0.7	0.7	1.3	15	58	52	33	22	0.9	1.0	0.7	0.9	41	1.0
98	0.7	0.7	0.6	0.5	0.6	0.8	14	21	26	23	6.7	0.7	0.9	0.6	0.7	22	0.8
99	0.6	0.6	0.5	0.4	0.5	0.7	12	15	18	19.2	0.9	0.6	0.9	0.5	0.6	17	0.6
99.5	0.5	0.5	0.4	0.4	0.4	0.6	0.9	14	1	18.7	0.7	0.5	0.8	0.4	0.5	13.7	0.5
99.8	0.4	0.4	0.3	0.3	0.3	0.4	0.7	1.0	0.7	0.9	0.6	0.4	0.8	0.3	0.4	0.8	0.4
99.9	0.3	0.4	0.3	0.3	0.3	0.4	0.6	0.8	0.6	0.7	0.5	0.4	0.8	0.3	0.3	0.7	0.4
99.95	0.3	0.3	0.3	0.2	0.3	0.3	0.5	0.6	0.5	0.6	0.4	0.3	0.8	0.3	0.3	0.5	0.3
99.99	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.5	0.3	0.2	0.7	0.2	0.2	0.3	0.2

Note: Based on daily values. Period of Record 1942 through 2000

SOUTH PLATTE RIVER AT DENVER GAGE FLOW DURATION - BASE CONDITIONS (5432.0 FT MSL POOL)

Percent of Time	Flow (cfs)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	8668	1041	1238	2335	6731	14115	9174	4255	8790	2063	4257	1512	600	2335	14115	8790	4257
0.05	6775	1041	1238	2335	6731	14115	9174	4255	8790	2063	4257	1512	600	1889	8339	7002	2162
0.1	6188	762	1114	2043	6624	8780	8909	4166	8091	1765	3145	1370	556	1644	7450	5169	1680
0.2	5575	563	888	1775	6214	7635	7963	3907	6213	1592	1857	1277	528	1403	6749	4333	1433
0.5	4507	426	628	1450	5275	6518	6150	3149	4374	1329	1442	1133	493	1076	5949	3296	1145
1	3575	366	476	1196	3670	5825	4950	2634	3408	1107	1158	761	439	729	5258	2510	856
2	2589	316	380	815	2624	5052	4071	2148	2252	855	892	636	393	548	4392	1864	611
5	1467	258	286	547	1378	3948	2983	1621	1309	613	529	464	329	385	3058	1293	437
10	844	221	243	416	957	2838	2230	1243	956	465	384	375	264	284	2112	926	331
15	595	202	217	341	720	2225	1805	991	779	378	299	304	233	239	1558	733	275
20	474	186	201	292	600	1719	1470	861	674	328	256	264	209	213	1169	623	241
30	332	163	179	220	432	953	987	648	537	255	204	224	179	182	712	473	201
40	248	145	161	181	337	608	671	511	436	213	175	193	158	161	509	369	175
50	198	129	144	157	265	471	501	422	348	184	149	172	145	143	400	292	154
60	165	113	126	139	201	374	406	338	275	157	132	153	133	125	323	236	138
70	139	100	112	116	154	299	330	275	224	135	116	136	120	108	246	188	123
80	115	83	97	96	112	215	252	216	177	110	102	120	106	92	174	149	109
85	103	71	88	85	91	181	217	183	154	98	93	112	98.8	81.1	145	129	100
90	88	61	76	71	69	145	164	148	124	83	80	100	89	67	112	108	88
95	67	48	56	49	25	107	116	114	97	70	69	79	70	51	75	84	72
98	44	37	41	26	15	57	87	91	65	59	55	62	48	35	23	65	54
99	28	31	33	18	12	20	69	76	44	49	48	50	35	25	15	52	43
99.5	18	26	25	14	10	12	52	62	29	47	46	29	28	19	12	41	33
99.8	13	22	17	11	9	9	18	48	21	44	43	18	23	14	10	29	22
99.9	11	20	11	10	9	8	12	28	19	43	41	17	21	11	8	22	19
99.95	9	19	10	9	9	7	10	20	18	41	40	16	20	10	7	19	18
99.99	7	18	10	8	8	5	10	19	16	39	37	14	18	8	5	16	15

Note: Based on daily values. Period of Record 1942 through 2000

SOUTH PLATTE RIVER AT DENVER GAGE FLOW DURATION - WITH PROJECT CONDITIONS (5437.0 FT MSL POOL)

Percent of Time Equalled or Exceeded	Flow (cfs)																
	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
0.01	8679	1038	1237	2333	6309	14113	6567	4199	8790	2057	4231	1491	598	2333	14113	8790	4231
0.05	6803	1038	1237	2333	6309	14113	6567	4199	8790	2057	4231	1491	598	1889	8361	6599	2169
0.1	6220	762	1114	2043	6242	8780	6496	4091	7886	1787	3201	1471	555	1640	7486	4902	1600
0.2	5609	563	888	1773	5973	7635	6224	3743	5722	1630	1838	1386	528	1415	6795	4296	1379
0.5	4527	432	628	1456	5302	6518	5620	3119	4307	1388	1393	1150	492	1034	6006	3249	1165
1	3557	361	469	1220	3433	5825	5059	2663	3380	1053	1151	769	438	716	5317	2457	853
2	2563	312	382	794	2705	5052	4251	2154	2036	856	883	618	397	543	4414	1834	603
5	1440	255	273	542	1333	3953	2939	1612	1271	585	527	451	329	378	3032	1276	427
10	836	217	229	410	950	2833	2227	1237	935	449	377	352	261	276	2114	926	323
15	589	199	207	335	709	2189	1819	1015	765	373	290	293	230	229	1546	736	268
20	471	183	192	286	576	1712	1446	865	662	325	251	253	209	207	1146	624	237
30	329	160	171	213	422	921	990	661	531	257	199	216	177	177	700	478	197
40	245	142	155	178	327	592	661	532	437	213	169	187	157	157	503	371	171
50	195	127	135	156	257	459	500	437	352	182	148	166	143	138	396	298	152
60	162	112	118	134	197	367	407	347	281	157	130	151	130	120	318	238	136
70	137	98	106	113	152	291	333	286	228	135	115	134	119	105	242	191	122
80	113	82	92	93	111	207	253	225	182	112	102	117	106	89	170	151	107
85	101	71	83	83	91	172	215	192	159	101	93	107	98	79	143	132	99
90	87	61	72	70	69	142	164	155	132	85	81	92	89	66	112	111	87
95	67	48	55	49	26	102	118	118	100	71	71	74	71	50	75	87	72
98	44	37	41	26	15	49	89	93	74	61	57	58	52	35	24	67	55
99	30	31	33	18	12	20	67	71	52	49	49	42	41	26	16	53	45
99.5	18	27	25	14	10	12	52	47	40	46	47	24	32	19	12	43	35
99.8	13	22	17	11	10	9	22	37	31	43	44	19	25	14	10	35	23
99.9	11	20	11	10	10	8	14	32	29	41	42	18	22	11	8	31	19
99.95	9	19	10	9	9	7	10	30	27	39	40	17	20	10	7	29	18
99.99	7	18	10	8	9	5	7	28	25	36	38	16	18	8	5	26	16

Note: Based on daily values. Period of Record 1942 through 2000

SOUTH PLATTE RIVER AT DENVER GAGE FLOW DURATION - WITH PROJECT CONDITIONS (5444.0 FT MSL POOL)

Percent of Time	Flow (cfs)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	8664	1033	1236	2331	6309	14174	6320	4212	8790	2051	4073	1456	596	2331	14174	8790	4073
0.05	6776	1033	1236	2331	6309	14174	6320	4212	8790	2051	4073	1456	596	1890	8362	4741	2173
0.1	6190	762	1113	2043	6242	8809	6250	4040	5271	1767	3148	1438	556	1646	7490	4375	1606
0.2	5569	563	888	1777	5973	7696	5991	3654	4523	1595	1839	1359	525	1411	6801	4011	1352
0.5	4476	419	628	1452	5302	6607	5427	2992	3988	1298	1378	1140	490	1068	6012	3068	1100
1	3500	358	476	1231	3607	5926	4923	2558	3127	1052	1094	755	442	711	5320	2396	817
2	2524	308	380	794	2541	5156	4153	2129	2084	825	838	606	394	536	4404	1814	581
5	1407	252	270	534	1337	3942	2926	1577	1275	566	490	443	323	368	2998	1259	414
10	813	214	226	395	923	2796	2157	1218	934	441	340	341	254	266	2073	925	310
15	582	192	202	322	673	2189	1717	1014	759	370	277	290	223	223	1481	733	261
20	464	176	188	269	544	1670	1403	860	665	322	245	252	203	199	1093	623	232
30	326	154	165	202	400	885	908	665	540	260	199	215	173	170	665	480	195
40	242	137	145	171	305	576	641	543	446	219	170	184	154	149	488	379	168
50	193	123	130	147	240	441	495	444	361	189	149	164	140	132	388	304	150
60	159	110	115	126	182	358	409	355	293	165	132	148	128	116	306	245	135
70	135	97	103	108	144	279	338	295	238	143	117	132	117	102	230	200	121
80	112	82	91	89	102	196	255	230	194	119	103	114	104	87	162	159	106
85	100	71	81	77	84	161	214	196	171	106	93	104	96	76	135	140	97
90	85	61	70	63	61	135	163	154	145	89	80	88	87	64	106	118	85
95	64	48	54	45	24	96	122	116	116	72	69	72	68	49	67	91	70
98	42	37	41	25	15	40	93	83	88	61	52	57	51	35	22	68	53
99	28	31	33	18	12	17	74	49	65	49	48	40	41	25	16	53	43
99.5	18	27	25	14	10	12	53	35	52	44	46	21	32	19	13	42	34
99.8	13	22	17	11	10	9	29	27	43	40	43	18	25	14	10	33	21
99.9	11	20	11	10	10	8	23	24	38	36	41	17	22	11	9	26	19
99.95	9	19	10	9	9	7	20	10	10	20	40	16	20	10	8	18	17
99.99	7	18	10	8	9	5	17	10	10	19	37	14	18	8	6	10	15

Note: Based on daily values. Period of Record 1942 through 2000

SOUTH PLATTE RIVER AT HENDERSON GAGE FLOW DURATION - BASE CONDITIONS (5432.0 FT MSL POOL)

Percent of Time	Flow (cfs)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	16676	2635	2848	4646	11390	19606	19546	8685	11052	4150	6114	2038	1254	4646	19606	11052	6114
0.05	11159	2635	2848	4646	11390	19606	19546	8685	11052	4150	6114	2038	1254	4010	15493	10148	5203
0.1	9730	1223	2780	4396	10941	15537	12886	7679	10697	3680	5797	1847	1157	3231	12848	8603	2658
0.2	8199	1049	1847	3682	9549	12790	10305	6357	9506	2864	2843	1723	1130	2787	10942	6701	2314
0.5	6343	971	1249	2809	6476	9953	8811	4838	6160	2302	2420	1587	1030	1979	8858	4680	1792
1	5033	863	988	2202	4919	7919	7967	4067	4514	1928	1952	1392	954	1419	7439	3776	1418
2	3797	773	821	1603	3662	6603	6723	3384	3443	1360	1460	1120	861	1064	6108	2950	1068
5	2259	680	687	1051	1916	5163	4758	2518	1924	931	838	860	688	785	4400	1945	770
10	1348	590	594	806	1324	3771	3616	1856	1265	687	606	630	581	657	3104	1365	607
15	976	526	522	687	1049	2871	2955	1533	998	551	504	547	501	567	2346	1083	517
20	773	490	461	593	862	2262	2507	1329	878	498	452	475	437	502	1840	915	455
30	570	398	402	447	585	1377	1852	1014	673	407	379	397	354	415	1240	695	375
40	454	339	349	373	461	907	1427	842	568	355	322	330	315	353	884	564	322
50	373	278	299	311	360	646	1132	708	481	310	276	287	269	297	638	474	277
60	311	239	248	256	287	498	878	612	412	267	246	252	240	247	489	391	246
70	253	191	212	212	225	398	688	517	356	232	210	213	212	206	374	330	212
80	203	131	164	162	167	321	512	422	296	198	166	174	165	152	278	261	169
85	171	108	136	136	137	270	440	377	248	180	144	152	142	127	230	230	146
90	137	89	116	117	107	226	359	320	204	156	122	128	119	105	178	196	123
95	101	70	93	88	70	169	267	254	157	124	93	103	95	80	120	154	97
98	73	51	72	59	32	114	175	201	113	96	76	79	69	58	70	113	76
99	56	44	61	42	21	78	129	165	92	81	71	72	57	47	38	93	66
99.5	41	39	52	25	17	48	104	121	75	70	60	63	48	38	23	77	55
99.8	26	35	48	20	13	27	44	93	47	52	49	53	37	27	15	60	45
99.9	18	32	46	19	11	10	13	58	39	48	46	50	29	20	11	43	39
99.95	13	30	45	18	10	9	10	30	10	45	44	48	10	19	9	34	33
99.99	7	27	42	17	6	8	7	26	7	41	40	44	8	17	6	9	9

Note: Based on daily values. Period of Record 1942 through 2000

SOUTH PLATTE RIVER AT HENDERSON GAGE FLOW DURATION - WITH PROJECT CONDITIONS (5437.0 FT MSL POOL)

Percent of Time	Flow (cfs)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	14768	2633	2847	4645	11546	19609	14902	8688	11052	4159	6130	2034	1250	4645	19609	11052	6130
0.05	10969	2633	2847	4645	11546	19609	14902	8688	11052	4159	6130	2034	1250	4010	14185	10147	5206
0.1	9401	1223	2779	4384	10340	15530	13087	7678	10697	3685	5808	1842	1157	3231	12781	8602	2664
0.2	8135	1049	1847	3653	8412	12512	9715	6356	9504	2863	2845	1713	1130	2787	10534	6700	2280
0.5	6419	971	1249	2857	6286	9641	8595	4836	6161	2302	2406	1570	1030	1978	8634	4675	1752
1	5092	863	988	2232	4922	8034	7911	4049	4503	1928	1880	1384	948	1389	7478	3749	1413
2	3796	772	809	1570	3582	6745	6791	3356	3401	1342	1462	1105	861	1061	6195	2930	1061
5	2246	677	679	1042	1914	5201	4866	2546	1879	934	834	841	688	780	4443	1938	762
10	1343	582	582	798	1305	3850	3666	1836	1264	665	599	616	576	647	3074	1381	597
15	973	523	498	678	1034	2782	2974	1552	990	551	498	542	500	556	2326	1079	511
20	770	487	444	583	842	2220	2512	1351	874	496	449	466	438	494	1824	918	451
30	565	395	392	444	578	1344	1818	1031	673	405	372	388	353	408	1225	697	369
40	450	336	340	371	454	893	1423	856	571	354	317	323	313	348	875	566	318
50	370	275	294	308	353	639	1125	716	483	308	276	281	266	293	636	473	275
60	308	237	243	253	283	488	878	614	420	265	245	249	238	244	483	393	243
70	251	189	206	209	222	389	689	520	363	232	209	210	210	202	369	331	210
80	201	131	162	160	165	314	513	425	299	199	166	171	168	151	274	262	168
85	170	108	134	134	135	265	436	376	256	180	141	148	147	125	226	232	145
90	136	88	114	114	104	218	360	325	213	157	120	122	122	104	175	199	121
95	100	69	93	86	69	158	270	253	163	128	94	98	96	79	117	157	96
98	72	51	72	58	32	101	181	204	119	103	76	76	68	58	67	117	75
99	56	44	60	40	21	65	129	165	97	86	72	68	59	47	36	98	66
99.5	40	39	52	25	17	40	105	121	73	74	67	57	48	37	22	80	57
99.8	24	34	48	20	13	18	44	87	39	63	62	45	37	27	15	64	45
99.9	17	32	47	19	11	10	13	69	13	48	60	34	29	20	11	36	37
99.95	12	30	45	18	10	9	10	30	10	45	58	30	10	19	9	19	29
99.99	7	27	43	17	6	8	6	26	7	41	56	30	8	17	6	9	9

Note: Based on daily values. Period of Record 1942 through 2000

SOUTH PLATTE RIVER AT HENDERSON GAGE FLOW DURATION - WITH PROJECT CONDITIONS (5444.0 FT MSL POOL)

Percent of Time	Flow (cfs)																
Equalled or Exceeded	**Annual**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
0.01	14768	2629	2845	4644	11546	19626	14823	8695	11053	4174	6139	2026	1243	4644	19626	11053	6139
0.05	10855	2629	2845	4644	11546	19626	14823	8695	11053	4174	6139	2026	1243	4009	14185	9509	5208
0.1	9264	1223	2778	4395	10340	15538	13075	7685	10186	3693	5815	1844	1157	3231	12781	8318	2623
0.2	8010	1049	1847	3682	8422	12810	9716	6223	8799	2863	2823	1715	1130	2789	10544	6565	2203
0.5	6297	971	1249	2811	6224	9590	8602	4682	5661	2306	2311	1570	1031	1939	8555	4401	1720
1	4990	864	988	2163	4799	7679	7919	3956	4109	1914	1836	1384	942	1390	7336	3599	1398
2	3719	768	810	1566	3454	6508	6761	3323	3171	1295	1415	1097	847	1051	6080	2874	1049
5	2220	678	679	1035	1897	5144	4775	2527	1852	915	771	818	682	774	4373	1920	734
10	1328	576	582	790	1275	3702	3576	1853	1263	654	589	613	562	645	3020	1373	590
15	960	520	495	673	1014	2771	2899	1559	988	551	491	534	497	550	2297	1080	505
20	762	477	440	570	807	2192	2463	1355	868	494	443	464	433	486	1804	918	446
30	562	392	384	435	556	1319	1827	1037	681	406	369	379	349	399	1201	705	363
40	445	332	336	360	428	877	1398	856	573	358	315	321	311	342	858	571	316
50	366	274	287	295	334	629	1101	725	491	311	274	280	262	287	628	476	273
60	305	235	237	244	267	479	867	622	424	270	245	248	235	239	473	397	242
70	249	185	202	206	209	382	700	528	369	236	210	211	209	199	361	335	210
80	201	131	160	156	158	305	518	434	311	204	168	169	166	149	266	270	168
85	170	107	133	130	130	263	443	380	274	186	144	145	144	123	217	239	144
90	135	88	111	107	96	212	364	322	235	163	121	121	122	101	168	209	121
95	99	69	93	79	63	152	272	251	186	135	95	97	94	78	113	165	95
98	70	51	71	54	30	91	183	204	135	110	74	74	69	56	61	125	73
99	52	44	60	36	20	58	127	158	108	99	63	63	59	46	32	107	61
99.5	38	39	52	23	16	27	112	121	74	87	50	54	47	37	22	88	50
99.8	23	35	48	19	12	13	65	89	40	66	49	43	37	25	14	63	41
99.9	16	32	47	19	10	9	30	68	10	49	48	33	29	20	10	39	35
99.95	11	30	45	18	8	9	28	30	8	47	48	30	10	19	8	17	29
99.99	7	27	43	17	5	7	26	26	5	42	47	30	8	17	5	7	9

Note: Based on daily values. Period of Record 1942 through 2000