Alder Creek Watershed Assessment and Management Plan

River Geomorphology and Hydrology Component

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1. INTRODUCTION

The Alder Creek basin is located on the eastern margin of the Sacramento Valley just south of Folsom, California (Figure 1.1). Alder Creek drains 11 square miles from the base of the Sierra Nevada foothills to the American River at Lake Natoma. A relatively small portion of the watershed, the area north of Highway 50, has been developed or is still undergoing development within the City of Folsom. The majority of the watershed is presently undeveloped but is expected to build out over the next 10 to 20 years, much of it within the City of Folsom Sphere of Influence (SOI; see Figure 1.1), and the remainder in unincorporated Sacramento County. Development in the SOI is described in the City of Folsom SOI Conceptual Land Use Plan (City of Folsom, 2007) whereas the area west of Prairie City Road will be developed as part of the Easton Project (County of Sacramento, 2008).

The City of Folsom applied for and was awarded a CALFED grant in 2007 to conduct a watershed assessment of Alder Creek and examine the effects of the proposed build out on water quality, river geomorphology, and riparian and aquatic ecology. The grant is administered by the California State Department of Water Resources.

This report contains the stream geomorphology, water quality (sediment), and hydrology components of the watershed assessment conducted by Northwest Hydraulic Consultants (**nhc**) for EDAW, Inc. EDAW is responsible for the biologic and ecologic components of the watershed assessment as well as project management, environmental permitting and stakeholder coordination. The results of the watershed assessment are intended for use by the City of Folsom as a long-term guidance document to set conditions on future development and to develop meaningful projects that preserve and enhance natural resource value and function of the Alder Creek stream network and riparian corridor.

The goals of **nhc**'s component of the watershed assessment are to:

1. Develop baseline information on the physical characteristics of the Alder Creek watershed, specifically geologic, geomorphic, hydrologic, and hydraulic conditions in the stream network.

2. Identify the geomorphic history of the watershed; include significant events that have affected stream system evolution and identify how the system changed as a result.

3. Assess existing channel stability and hydraulic characteristics in the stream network and evaluate the impacts of projected future changes in basin hydrology and land use on stream geomorphology.

4. Provide specific recommendations for design and development in the watershed that address channel stability, habitat and water quality concerns.

This report is divided into three main parts, i) Alder Creek Watershed, ii) Hydromodification Analysis, and iii) Watershed Management Recommendations. Part one addresses objectives one and two whereas parts two and three address objectives three and four, respectively. A summary and conclusions is provided in part four of this report.

2. ALDER CREEK WATERSHED

The following sections describe the topography, geology, soils, geomorphology, and disturbance history of the Alder Creek watershed. These watershed characteristics provide an important background for understanding existing geomorphic conditions in the Alder Creek stream network.

2.1 TOPOGRAPHY

Located on the margin between the Sacramento Valley and Sierra Nevada Mountains, the Alder Creek basin is characterized by undulating topography that becomes increasingly more hilly with distance upslope (Figure 2.1). The majority of the watershed lies below 500 ft elevation with the eastern edge rising rapidly into the foothills just east of Placerville Road. Mt. Carpenter is the highest point in the watershed at 828 ft and the lowest point is at Lake Natoma, a small afterbay for Folsom Dam at approximately 125 ft elevation.

For this study, the Alder Creek basin was divided eight subwatersheds based on the location of tributary inflows to Alder Creek (Figure 2.2). General characteristics of each subwatershed are summarized in Table 2.1.

Table 2.1 Alder Creek Stream Network Characteristics by Subwatershed

Subwatershed	Area (mi^2)	Elevation (ft)		Relief (ft)	Stream Length (mi)	Average Stream Slope
		Min	Max			
ALDER-1	1.82	125	312	187	2.55	0.015
ALDER-2	1.69	243	410	167	3.43	0.016
ALDER-3	0.80	322	528	206	2.35	0.009
TRIB-1	0.64	243	367	124	1.44	0.014
TRIB-2	1.74	294	828	534	3.32	0.023
TRIB-3	2.23	294	811	517	6.81	0.029
BROAD-1	0.56	252	375	123	0.88	0.020
BROAD-2	1.48	259	702	443	2.15	0.015
Total Watershed	11.0	125	828	703	22.7	0.019

Topographic data shown in Table 2.1 were developed from USGS 10 m DEM data in GIS (USGS, 2001). The Alder Creek stream network was digitized from 2005 air photographs (USDA, 2005) and updated by comparison with recent (2008) aerial photography on Google Earth. Most updates were made to account for recent construction activities north of Highway 50. Note that a gap in the stream network in subwatershed TRIB-2 is the result of an underground storm drain (see Figure 1.1).

2.2 LAND USE

Land use in the watershed can be divided into three distinct areas by Highway 50 and Prairie City Road (Figure 2.3). The area north of Highway 50 has been almost completely developed by the City of Folsom for residential and light commercial land uses. Runoff generated from this area passes through a series of detention ponds designed to reduce peak flows to pre-developed rates as required by the City of Folsom. In contrast, the area south of Highway 50 is almost entirely undeveloped. Dredge tailings from historic gold mining dominate much of the basin west of Prairie City Road whereas oak woodland and open grassland used predominantly for grazing occupy land to the east. Near surface bedrock in the middle and upper watershed promotes a high water table and various types of wetland habitat including vernal pools, seasonal wetlands and emergent marshes (County of Sacramento, 2008). Oak woodland is found predominantly along Alder Creek and increases with distance downstream, particularly downstream of Prairie City Road.

2.3 GEOLOGY

Figure 2.4 shows the geology of the Alder Creek basin. The Copper Hill and Gopher Ridge Volcanics underlie much of the middle and upper watershed and are composed of metamorphosed mafic to felsic pyroclastic rocks with some pillow lava and minor felsic porphyrite (Wagner et al., 1987). Volcanic activity in the region occurred about 200 million years ago during the Nevada Orogeny, a period of mountain building which formed the ancestral Sierra Nevada Range, a range much lower than that observed today. The Salt Springs Slate was also formed during this period as a result of tectonic metamorphism. Over time, these rocks were metamorphosed again through a series of compressive faulting events along the Sierra Nevada Range which continued through the middle and late Tertiary Period (about 30 million to 5 million years ago) and produced the northwest-southeast trending rock alignment observed today (Norris and Webb, 1990).

The lower part of the watershed, downstream of Prairie City Road, is covered almost entirely by dredge tailings consisting of reworked alluvial deposits bordering the American River. Extensive areas along the American River were mined for placer deposits from 1849 until the 1960s (Clark, 2005). Dredge tailings grade east along Alder Creek into consolidated gravel, sand and silt of the Laguna Formation as well as the Ione Formation, composed of quartzose sandstone interbedded with kaolinitic clay in the vicinity of Prairie City Road. Both these rock units are composed of consolidated sedimentary deposits eroded from the Sierra Nevada Range during the Tertiary Period (66 million to 2 million years ago).

The Alder Creek basin lies just west of the Foothills Fault System, a series of faults located along the eastern Sacramento Valley margin at the base of the Sierra Nevada Mountains (Jennings, 1994). Although the fault system is very extensive and exhibits numerous large fault zones, there is no evidence of fault displacement or earthquake activity during the Quaternary Period (the last 1.6 million years; Jennings, 1994).

2.4 SOILS

Alder Creek soils are shown in Figure 2.5 and can be divided into four main soil series, namely: Auburn, Argonaut, Whiterock, and Xerorthents, the latter consisting of mine and dredge tailing deposits (NRCS, 2007). Xerorthents occupy much of the western part of Alder Creek from Prairie City Road to Lake Natoma and are primarily composed of loose sand, gravel, and cobbles. Auburn, Argonaut, and Whiterock soil series dominate the middle and eastern parts of the watershed. These soils form a thin mantle over the underlying bedrock and rock outcrops are common. Auburn soils are characterized by silty loam ranging from 10 to 28 inch depths. Argonaut series soils are coarser, consisting of gravelly loam and also deeper, ranging from 20 to 40 inches thick. In contrast, Whiterock series soils are loamy and very thin, extending between 4 and 14 inches to near surface bedrock. The National Resource Conservation Service (NRCS) classifies each of these soil series as well to excessively drained.

2.5 GEOMORPHOLOGY

This section documents existing geomorphic conditions in the Alder Creek stream network. The discussion is based on background information collected for this study and a two day field inspection of 15 stream sites conducted in February 2008 (Figure 2.6). The results of the field inspection are provided first, followed by a discussion of existing conditions in each subwatershed.

2.5.1 Field Inspection

Field observations, ground photos, cross-section and long profile surveys, and bed material counts were obtained at each field inspection site. These data were collected for the geomorphic assessment as well as the hydromodification analysis discussed later in this report. Cross-sections, long profiles and bed material gradations for Alder Creek sites downstream of Prairie City Road were obtained from existing information collected by E-Corp (Bill Christner, pers. comm.). Cross-section surveys were collected for **nhc** by Mackay & Somps in the middle watershed (Sites 5, 6, 7, 8 and 9) and developed from existing 1 ft and 2 ft contour topography of the SOI and lower Alder Creek for Sites 3, 11, 12, 13 and 14 (Mackay & Somps, 2005, 2006). Ground photographs, survey data and bed material count information is provided in Appendix 1.

Table 2.2 summarizes channel characteristics at each field inspection site. Channel width and depth are of the bankfull channel, estimated from cross-section surveys by a break in

Table 2.2a Summary of Alder Creek Field Inspection Site Observations

Site ID	Stream Channel			Stream Type	Bank material	Bed material	Notes
	Width[1] (ft)	Depth (ft)	Slope				
ECORP-1	25	2.5	0.038	Pool-riffle	road fill and bedrock	gravel and cobble	Confined, narrow reach just downstream of Prairie City Road bridge. The left bank slopes steeply upward whereas the right bank rises more gradually. Bedrock control appears on both stream bed and left bank. A large gravel bar (20' x 100') is located downstream from this site and a large beaver dam forms a pond approximately 300 ft upstream of the bridge. The channel appears stable and no significant stream bank or bed erosion is observed.
ECORP-2	25	2.5	0.009	Plane-bed	medium to coarse sand	gravel and cobble	Confined reach with moderately sloping banks rising to hummocky dredge spoil deposits adjacent to channel. Prodigious Himalayan Blackberry lines the stream banks. No significant bedforms appear on the stream bed; however, a large gravel bar (25' x 60') is located on the left bank at a bend approximately 100 ft downstream of ECORP-2 followed by a deep pool. The channel appears stable with no apparent bank or bed erosion.
ECORP-3	30	3	0.018	Plane-bed	sand to cobble sizes	gravel and cobble	Confined reach with a steep, high left bank and gradually sloping right bank with narrow floodplain surface. Abundant blackberry lines both banks which exhibit a heterogeneous mixture of silt to cobble sizes characteristic of dredge spoil. The creek is straight with no significant bedforms or instream features. No stream bank or bed erosion is observed and the channel appears stable. A high water mark from the Jan 4th peak flow (1460 cfs) was observed approximately 5 ft above the stream bed.
ECORP-4	40	4	0.005	Plane-bed	sand to cobble sizes	gravel and cobble	Entrenched reach with high, steep banks covered in dense blackberry bushes. The creek is straight and no significant bedforms are observed. The channel is stable and exhibits no bed or bank erosion features.
Stagegage	35	2.5	0.009	Pool-riffle / Plane-bed	sand to cobble sizes	gravel and cobble	Confined reach with moderately sloping banks and narrow floodplain. Abundant blackberry bushes cover stream banks composed of dredge spoil deposits (a mix of silt to cobble sizes). A downed tree in the channel forms bar and riffle morphology in otherwise straight, plane-bed reach. The channel is stable with no apparent bed or bank erosion. ECORP noted bedrock control on the stream bed 180 ft upstream of this site.
3	6	1.5	0.012	Plane-bed	fine sand and silt	sand and minor gravel	this stream appears as a small ditch that flows into a detention basin adjacent Alder Creek further downstream. The reach is straight with no bends or bedforms on the channel bed. Abundant underbrush, mainly blackberry, lines the banks. Large woody debris is observed laying across the channel but not in the stream. Adjacent dredge spoil creates hummocky ground that obscures the floodplain. The reach appears stable with no observed bed or bank erosion.

Note: Left bank and right bank are with reference to looking in the downstream direction

Table 2.2b Summary of Alder Creek Field Inspection Site Observations

Site ID	Stream Channel			Stream Type	Bank material	Bed material	Notes
	Width[1] (ft)	Depth (ft)	Slope				
5	20	2.5	0.004	Pool-riffle	medium to coarse sand	gravel and cobble	Near-surface bedrock control on the stream bed creates a wide, shallow stream at this site that grades into a narrow confined stream section immediately downstream along a steep rock slope. The channel appears stable with very minor bank erosion is observed on the left bank. Banks are covered in short grass due to active grazing and composed of sandy bank material. Some instream gravel and cobble material is poorly rounded indicating local sediment supply.
6	8	1.5	0.009	Pool-riffle	fine to coarse sand	coarse sand and gravel	This small stream is confined in a narrow, v-shaped valley with steep banks and a very narrow, discontinuous floodplain. Bedrock control is common along the bed and banks. The channel appears stable with no bed or bank erosion. Grasses and occasional blackberry bushes populate stream banks and the area is actively grazed.
7	10	1	0.011	Pool-riffle	silt to cobble sizes	gravel and cobbles	This small tributary meanders through hummocky, reworked ground – possibly dredge spoil? The area is actively grazed and stream banks are covered in cropped grass. A point bar (8' x 4') composed of cobble and gravel is present on the inner stream bend whereas minor bank erosion is observed on the outer bend. Some bedrock control is observed on the right bank floodplain; the floodplain is broad and well defined at this site.
8	10	2	0.013	Plane-bed	silt to cobble sizes	gravel and cobbles	Bordered by hillslopes, this small tributary flows in a straight, narrow channel with no bedforms. Bedrock control outcrops on the bed and banks, the latter covered by grasses and a few willows. The channel is stable with no significant bed or bank erosion. A narrow floodplain generally confined to 50 ft or less is seen on both the right and left banks. The stream enters a culvert and passes under Highway 50 approximately 200 ft downstream of site.
9	30	2	0.010	Pool-riffle	silt and sand	coarse sand and gravel	The channel flows through a rocky narrows in this section. No floodplain is present and the banks slope up immediately adjacent to the channel. Abundant bedrock control is present on the bed and banks and grass covers either bank. The area is actively grazed and the channel is stable with no bed or bank erosion. No depositional features are observed in the stream channel.
11	10	1	0.002	Plane-bed / Pool-riffle	silt and sand	sand and small gravel	This upland channel is wide and shallow, controlled by the very rocky terrain and thin soils. The stream is stable with no bed or bank erosion and significant bedrock control. No significant bedforms are observed other than occasional riffle at a rock outcrop. Short grasses cover this active grazing area.

Note: Left bank and right bank are with reference to looking in the downstream direction

Table 2.2c Summary of Alder Creek Field Inspection Site Observations

Site ID	Stream Channel			Stream Type	Bank material	Bed material	Notes
	Width[1] (ft)	Depth (ft)	Slope				
12, 13, 14	8 – 15	3	0.006 to 0.012	N/A	N/A	N/A	Limited access to site, observed from road. Some local erosion along the stream is caused by active grazing and trampling. The channel is lined with short grasses and appears stable with a discontinuous floodplain in an undulating hilly area. No bedforms were observed in the stream.

Note: Left bank and right bank are with reference to looking in the downstream direction

slope at the top of the stream bank and by changes in vegetation cover (Williams, 1978). Stream types in Table 2.2 refer to large-scale bedforms on the channel bed, namely pool-riffle or plane-bed. Pool-riffle morphology is characterized by alternating areas of shallow, rapid flow over coarser bed material followed by deeper pools with more gradual flow and finer-grained bed material. Plane- bed streams exhibit no large-scale bedforms, are relatively flat along the stream bed, and have more uniform bed material characteristics. Other channel characteristics in Table 2.2 are discussed in the next section.

2.5.2 Existing Conditions

This section describes geomorphic conditions in the Alder Creek stream network for each of the eight subwatersheds in the basin (see Figure 2.6).

<u>ALDER-1</u>

The ALDER-1 subwatershed covers 1.8 square miles and contains the lowermost section of Alder Creek (see Figure 2.6). This 2.6 mile reach is a relatively straight, perennially flowing stream extending from Folsom Blvd. to Prairie City Road. Lake Natoma provides a base level control at the downstream end of the reach and the Prairie City crossing is bedrock controlled. A dam is located approximately 2,000 ft upstream of Folsom Blvd. Estimated to be about 25 ft high, the dam also provides a base level control and creates a backwater area that extends upstream approximately 1,500 ft during base flow conditions. The reservoir behind the dam appeared to be mostly full of sediment during the field inspection.

This reach of Alder Creek exhibits a nearly continuous riparian corridor of oak woodland and the most riparian cover of any stream corridor in the watershed (see Figure 2.3). The riparian area is bordered by dredge tailings which produce a hummocky and irregular surface in many areas adjacent to the stream channel, mainly on the south side of the creek. The south side appears as an irregular bench surface near the creek that rises steeply into hillslopes further south, some of which appear as nearly vertical cuts due to partial excavation by dredges. Hillslopes also border Alder Creek to the north along Highway 50.

Field inspection sites ECORP-1, 2, 3, 4 and Stagegage revealed a narrow and confined, stable channel with either pool-riffle or plane-bed stream morphology. All field inspection sites were characterized by a discontinuous channel floodplain confined by adjacent hillslopes and dredge tailings. No bed or bank erosion was observed. Channel bed material was predominantly gravel and cobbles with some instream woody debris and occasional bar surfaces limited in width by adjacent bank slopes.

The mouth of Alder Creek was inundated following the completion of Lake Natoma in 1955, forming Alder Creek pond (the pond). The pond is located at the downstream terminus of Alder Creek, between Folsom Blvd. and Highway 50. Alder Creek flows into the pond downstream of culverts beneath Folsom Blvd and to Lake Natoma through culverts beneath Highway 50. The pond ranges from about 5 to 10 acres in size, depending on water surface elevations in Lake Natoma, operated by the Bureau of Reclamation as an afterbay for Folsom Reservoir. Daily and seasonal operation of Lake Natoma results in fluctuations in water surface elevation that affect the pond's size and depth. Sediment from the Alder Creek watershed is deposited on the delta of Alder Creek, however surveys indicating the rate of growth or sedimentary characteristics of the delta or deposition within the pond are not available.

The twin box culverts (10'x10' barrels) underneath Folsom Boulevard do not appear to be affected by sediment deposition; however minor blockage by debris during high flow events may occur. Field inspections completed on this portion of the creek indicate no evidence of any significant scour or deposition of sediment in the vicinity of the culvert. Bed invert elevations are controlled by large boulders placed on the channel invert immediately downstream of Folsom Boulevard, and relatively immobile gravel and cobble riffles are noted in the channel both immediately upstream and downstream of Folsom Boulevard.

Circulation within the pond is limited, especially during low flow periods of Alder Creek. The twin box culverts (~10'x10' as scaled from Caltrans "as built" plans) underneath Highway 50 limit wind or current driven circulation from Lake Natoma into the pond as well. Extended periods of time of low flow from Alder Creek itself also leads to limited through flow circulation within this impounded embayment of Lake Natoma, resulting in impaired water quality of the pond.

TRIB-1

The TRIB-1 subwatershed covers 0.64 square miles and contains a small tributary to Alder creek. Land cover consists of oak woodland in the lower watershed and along the stream channel from the tributary mouth to Aerojet Road. Grassland and commercial land use on Aerojet property cover the remainder of this subbasin upstream of Aerojet Road.

The stream channel at Site 3, near the confluence with Alder Creek (see Figure 2.6), appears as a fairly straight, small ditch (see Appendix 1 – Field Photos). The stream bed is about 2 feet wide and appears stable with no bed or bank erosion. The stream flows into a settling pond just downstream of this site that empties through a culvert into Alder Creek.

ALDER-2

The ALDER-2 subwatershed is 1.69 square miles in size and contains 3.43 miles of stream, 2.6 miles of which is Alder Creek. Four tributaries flow into Alder Creek in this subwatershed. Two major tributaries (BROAD-1 and BROAD-2) drain into the creek from developed areas in the City of Folsom north of Highway 50 whereas two small streams drain north into Alder Creek from stock ponds (see Figure 2.6). Oak woodland persists along Alder Creek in ALDER-2 although it is much less dense than downstream of Prairie City Road. The remainder of the watershed land cover is grassland, mostly used for grazing, with some commercial land use in a small area north of Highway 50.

Topography in the ALDER-2 subwatershed is characterized by hilly, rocky terrain with much of the creek bordered by steep hillslopes (Mackay & Somps, 2006). Consequently, the floodplain surface is typically narrow or absent, particularly upstream of the BROAD-2 confluence where hillslopes increasingly confine the stream channel. Whiterock loam, the predominant soil type in ALDER-2 (See Figure 2.5), is very shallow and provides only a thin cover over underlying bedrock, usually a foot or less. Field inspection sites 5 and 9 both exhibit wide, shallow channel cross-sections due to bedrock control on the stream bed at both sites. No bed or bank erosion was observed at either site and pool-riffle bed morphology is largely influenced by bedrock controls along the stream bed at both locations.

Undeveloped Upper Watershed

The undeveloped upper watershed consists of subwatersheds ALDER-3, TRIB-3, and TRIB-2 south of Highway 50. This area occupies four square miles, about one third of the watershed, and contains 11.8 miles of stream channels. These streams consist of small, ephemeral drainages that convey runoff during the wetter months and run dry in summer. The undeveloped upper watershed is characterized almost entirely by rocky, undulating topography covered with grasslands and used for cattle grazing. No riparian cover is present along stream channels. Channel pattern is largely influenced by near-surface bedrock controls on the stream bed and banks.

Field inspection site 11, 12, 13, and 14 are located in the undeveloped upper watershed (see Figure 2.6). Due to property access restrictions, only Site 11 was visited on foot whereas Sites 12, 13, and 14 were viewed from the road. Stream channels at all inspection sites appeared stable with minor, localized bank erosion in some areas. Bedrock control along the bed and banks was prominent along the stream at Site 11 as were frequent bedrock outcrops and thin soil cover in the surrounding landscape.

Developed Upper Watershed

The developed upper watershed consists of the Broadstone area in the City of Folsom (BROAD-1 and BROAD-2) and ongoing development to the east in subwatershed TRIB-2 north of Highway 50 (see Figure 2.6). This area covers 2.8 square miles and contains 3.8 miles of stream channel that generally flow in narrow 'greenbelt' corridors within the developed area. Several water retention basins appear in the BROAD-1 and BROAD-2 subwatersheds. Aerial photos show the stream segment north of Highway 50 in subwatershed TRIB-2 entering a storm drain at Cavitt Drive. It appears to be routed underground for some distance before emerging south of Highway 50 although this was not verified in the field. Streams in the developed upper watershed were not visited during the field inspection, except at Site 8 just north of Highway 50 (see Figure 2.6). Similar to upland areas south of Highway 50, Site 8 exhibited bedrock control on the stream bed with no indications of bed or bank erosion or channel instability. Field inspection sites 6 and 7 are located at the mouth of subwatersheds BROAD-1 and BROAD-2, respectively. Both sites are located south of Highway 50 and exhibit stable channels with significant bedrock control.

2.6 HISTORICAL GEOMORPHOLOGY

Alder Creek and its surrounding watershed have been altered by historical activities that include extensive placer mining, flood control operations, water diversions, and urban development. These activities and their impact on the evolution of the Alder Creek stream network, and particularly lower Alder Creek, are documented in this section. The Folsom History Museum (2008) and a history of gold districts in California by Clark (2005) were the main sources of historical information used for this section.

2.6.1 Significant Events

Significant changes in the Alder Creek watershed began with the gold rush in 1849, a time when the population exploded with thousands of men arriving in the region. Mining camps rapidly appeared along the American River and displaced the local Maidu villages. New communities included Folsom, Mormon Bar, and Prairie City. Prairie City was located partly in the Alder Creek watershed, near the present day intersection of Prairie City Road and Highway 50. Mining on Alder Creek was concentrated on the lower mile or so of the creek during the early years of the gold rush, in addition to mining camps extending southwest along the American River. In its heyday in 1854, Prairie City numbered over 1000 with stores, hotels and a school, but bust followed boom and by the 1880s the town was virtually abandoned. The town of Folsom was laid out in 1855 as the first stop on the Sacramento Valley Railroad heading east from Sacramento and was completed in 1856. Folsom became an important center of trade and commerce between San Francisco and gold mining camps in the foothills and also became the western terminus of the Pony Express in 1860. Mining claims continued to be worked in the region through the 1890s, mainly by Chinese immigrants in later years.

The Natoma Water and Mining Company, later the Natomas Company, played a major role in the region’s history. Formed in 1851, the Natomas Company began water deliveries to the area around Prairie City starting in 1853. Water was delivered for miners who staked claims along the Natomas Company canal which carried water 20 miles from the south fork of the American River above Salmon Falls to Prairie City. The ditch reached Folsom in 1854. Additional ditches were added, some passing through the Alder Creek watershed, and their remnants can still be seen today. Examination of 1941 era historical topographic maps shows two ditches passing from north to south through the Alder Creek watershed (USGS, 1944). The first extends south from Willow Springs reservoir, which still exists today, and the second is located further east in the upper part of watershed.

The second phase of gold mining operations in the region began with the start of dredging operations in 1894, although dredging did not become a major industry until a few years later when bucket line dredging was perfected. Gold was the main product of dredging but other precious metals were extracted in smaller amounts (Clark, 2005). By 1900 the Natomas Company became the principal dredging operator in the district and, excluding a brief stoppage during World War 2, conducted operations until 1962 when the last active dredge was shut down. This marked the end of dredging operations in what is now called the Folsom Gold District (Clark, 2005), one of the largest gold districts in California. Approximately one billion cubic yards of gravel was dredged in this district, extending over ten miles from Folsom to Fair Oaks, and located primarily on the south bank of the American River.

The progressive history of dredging operations on lower Alder creek can be observed through comparison of 1937 aerial photos (Figure 2.7) with current photos (Figure 2.3). Ongoing expansion of dredging activity toward the east along lower Alder Creek can be observed between the two years. 1937 aerial photos also show significantly less vegetation cover along lower Alder Creek than observed today (Figure 2.3). This may be the result of a historical rise in the ground water table and consequent increase in vegetation cover caused by dredging operations on lower Alder Creek which lowered land elevations and construction of the Natoma Company dam which artificially raised the water table.

Dam construction on the American River and Alder Creek begins with the opening of Folsom Prison in 1880. The prison provided a cheap labor force for construction of the first dam at Folsom, completed in 1893 on the American River. By 1895 the powerhouse provided long distance transmission of electric power using alternating current, a rarity for the day. The dam was owned by the Natomas Company. A second dam was built on Alder Creek, presumably by the Natomas Company, but no specific mention is made of it in the literature reviewed for this report. The dam appears to have been constructed sometime between 1908 and 1937, the time period between which it appears on historical maps and aerial photos.

Work began on the contemporary Folsom Dam in 1952 and was completed in 1956. Nimbus dam and Lake Natoma were completed in 1955. The mouth of Alder Creek was inundated with the creation of Lake Natoma, operated as an afterbay for Folsom Reservoir by the U.S. Bureau of Reclamation. Aerojet established its Rancho Cordova facility on 13,500 acres in 1953, including much of the lower Alder Creek watershed. Highway 50 was constructed in the 1960s and development of the Alder Creek watershed north of Highway 50 began in the late 1990s and continues today.

2.6.2 Historical Channel Planform and Profile

Historical Channel Planform Shift

Historical maps of lower Alder Creek were available from 1893, 1908, 1937, 1952, 1967, and 1980. Orthorectified aerial photos were available from 2006. Figure 2.8 shows a historical planform shift map of lower Alder Creek from 1908 to 2006 from which three significant observations can be made. First, channel alignment downstream of the dam remains relatively unchanged from 1937 on, likely due to channel entrenchment by sediment hungry flows following dam construction. Second, the 1908 and 1937 channel planform shows two large meanders in the middle section of lower Alder Creek, meanders that are absent in later years. Given the close proximity of these meanders to Highway 50 it seems possible that the creek alignment was shifted south as part of highway construction. Lastly, examination of Figure 2.8 shows significantly greater variability in channel planform from 1908 to 1952 than from 1952 to 2006, indicating relative channel stability during the latter period. Dredging operations on lower Alder Creek prior to 1962 may have caused the greater channel planform variability observed during this era.

Historical Invert Profiles

Limited data were available regarding historical stream profiles of lower Alder Creek (Figure 2.9). 1908 and 1952 profiles in Figure 2.9 are from USGS topographic maps whereas 2005 data show base flow water surface elevations from 1 foot contour topography (Mackay & Somps, 2005). Examination of Figure 2.9 shows the abrupt change in stream profile caused by construction of the dam on Alder Creek. Downstream of the dam, Alder Creek shows stream incision from 1908 to 2005. This is expected given sediment trapping in the dam reservoir and subsequent erosion downstream of the dam. In contrast, Alder Creek upstream of the dam shows about 4 ft of stream aggradation from 1908 to 1952 with subsequent degradation back to 1908 levels by 2005. The cause is unclear but may be due to abundant sediment supply produced by dredging operations upstream of this area sometime between 1937 and 1962.

3. HYDROMODIFICATION ANALYSIS

3.1 APPROACH

A hydromodification analysis was used in this study to identify the potential for future urbanization and consequent changes in basin hydrology to cause channel instability in the Alder Creek stream network. Eight geomorphic index points representative of varying conditions and geomorphic environments in the stream network were selected for the hydromodification analysis (Figure 3.1). Hydrologic and hydraulic information was developed at each geomorphic index point and used to compute a shear stress index for existing and proposed hydrologic conditions. The index provides a scientifically based method to measure the likelihood of channel instability following changes in hydrologic regime, based on a shear stress index ratio developed from existing and proposed indexes. The shear stress index used in this study is based on average shear stress computations for a full range of flows at each index point. Detailed information regarding the development of hydrologic, hydraulic, and shear stress index values is provided below, followed by the results of the hydromodification analysis.

3.2 HYDROLOGY

This section documents the development of flow duration curves at geomorphic index points in the Alder Creek watershed (see Figure 3.1) for existing and proposed conditions, used later in the shear stress index calculations. No measured flow or precipitation data are available for the Alder Creek watershed nor have any continuous simulation models been developed from onsite or regional analyses. Consequently, flow duration curves were developed from alternate sources. The low flow component of the flow duration curve was developed from mean monthly flow records of 18 watersheds in northern California similar to Alder Creek whereas the high flow component of the flow duration curve was obtained from an event-based hydrologic model developed for the SOI area by Domenichelli & Associates (2007). Flow duration curves were developed for existing and proposed conditions at Prairie City Road, the downstream limit of the SOI. These curves were then scaled by basin area for use at each of the eight geomorphic index points. Details regarding the datasets and their development into flow duration curves at Prairie City Road are discussed below.

3.2.1 Low Flow Analysis

Mean monthly flow data from 18 gaged watersheds similar to Alder creek were used to develop the low flow component of existing and proposed condition flow duration curves at Prairie City Road. The 18 watersheds were selected based on the availability of USGS gage data, their location in Northern California and similar basin area and topographic characteristics to Alder Creek. Mean monthly flow data were normalized based on the ratio of mean annual precipitation in Alder Creek to each of the 18 watersheds and plotted against basin area for each month of the year. Mean monthly flow estimates at Prairie City Road were obtained from ordinary least-squares regression lines drawn through each of the twelve monthly datasets. Mean monthly flow data were assumed to represent existing conditions. Proposed condition mean monthly flows were obtained by multiplying the existing conditions dataset by 1.1, the difference between existing and proposed condition low flows from a hydromodification study conducted in the nearby Laguna Creek watershed (Geosyntec, 2007).

Mean monthly flow data were ranked and assigned a percent time of exceedance based on a one year time scale such that the lowest mean monthly flow was exceeded 100% of the time and the highest mean monthly flow exceeded 8% of the time (one month divided by one year). These are approximate estimates but are considered reasonable in the absence of flow data for Alder Creek. Results of the low flow analysis are summarized in Table 3.1.

Table 3.1 Low Flow Analysis Results for Prairie City Road

Percent Time Exceedance	Existing Conditions flow (cfs)	Proposed Conditions flow (cfs)
100%	0.12	0.13
92%	0.14	0.16
83%	0.30	0.33
75%	0.39	0.43
67%	0.73	0.80
58%	1.11	1.22
50%	1.75	1.91
42%	4.40	4.84
33%	4.48	4.93
25%	10.39	11.43
17%	11.05	12.15
8%	16.55	18.21

3.2.2 High Flow Analysis

The results of an event-based hydrologic model of the Folsom SOI by Domenichelli & Associates (2007) were used to develop the high flow component of existing and proposed condition flow duration curves at Prairie City Road. No extensive QA/QC review or detailed evaluation of the hydrologic model setup was conducted by **nhc** and the model results were used as is.

Flood hydrographs of design storms and peak flow data for the 2-yr, 5-yr, 10-yr, and 100-yr events at Prairie City Road formed the basis of the high flow analysis. Flood hydrographs were provided to **nhc** by Domenichelli & Associates for the 2-yr and 10-year existing condition 24-hr (hour) design storms and the 100-year proposed condition 24-hr design storm. These flood hydrographs were scaled using available peak flow data to develop a suite of 100-yr, 10-yr, 5-yr, and 2-yr 24-hour design storm flood hydrographs for both existing and proposed conditions.

Average flows were calculated from each design storm hydrograph for selected 1-hr through 24-hr time windows around the event peak (Figures 3.2 and 3.3). Flow duration curve information was developed by assigning a duration to each of the 1-hr through 24-hr average flows for the 2-yr, 5-yr, 10-yr, and 100-yr design storm events by computing the expected value of percent time each flow would occur over the 100 year range of design flows. For example, the expected value of the 100-year, 1-hr design storm occurs over 1-hr in a 100 year period. The 2-year, 1-hr flow occurs more frequently, once every two years or 50 hours every 100 years.

3.2.3 Flow Duration Curves

Flow duration data from the low flow and high flow analyses can be expressed in hours over a 100-year time interval as shown in Table 3.2 and plotted in Figure 3.4.

Table 3.2 Prairie City Road Flow Duration Analysis Results

Exceedance duration (hr)	Flow existing (cfs)	Flow prop. (cfs)
876000	0.12	0.13
803000	0.14	0.16
730000	0.30	0.33
657000	0.39	0.43
584000	0.73	0.80
511000	1.11	1.22
438000	1.73	1.91
365000	4.40	4.84
292000	4.48	4.93
219000	10.39	11.43
146000	11.05	12.15
73000	16.55	18.21
1200	236.5	324.6
1000	276.6	373.4
800	330.1	432.9
400	556.2	650.9
200	834.8	900.3
160	863.4	978.0
80	1287.9	1352.7
40	1677.4	1670.4
30	1785.7	1790.0
20	1969.8	2017.8
15	2134.1	2162.4
10	2308.6	2346.6
5	2478.2	2492.0
4	2519.7	2495.1
2	3300.3	3080.9
1.5	3575.6	3301.7
1	3867.9	3583.0

Note that Table 3.2 shows a jump in exceedance duration from 1,200 to 73,000 hours. This occurs at the break between available low flow and high flow datasets.

Flow duration curves for geomorphic index points (see Figure 3.1) were calculated by scaling the flow duration curves at Prairie City Road based on the ratio of contributing basin areas (Table 3.3).

Table 3.3 Geomorphic Index Point Basin Areas

Index Point	Stagegage	ECORP-2	Pilot	5	6	7	9	11	14
Basin Area (sq mi)	9.8	9.2	8.7	8.2	0.5	1.4	5.5	0.4	1.1

Table 3.4 summarizes existing and proposed condition flow durations for each index point.

Table 3.4 Existing and Proposed Condition Flow Durations at Index Points

	Prairie City Road		ECORP-2		Stage-gage	
Exceedance duration (hr)	**Flow existing (cfs)**	**Flow prop. (cfs)**	**Flow existing (cfs)**	**Flow prop. (cfs)**	**Flow existing (cfs)**	**Flow prop. (cfs)**
876000	0.12	0.13	0.13	0.14	0.13	0.15
803000	0.14	0.16	0.15	0.17	0.16	0.18
730000	0.30	0.33	0.32	0.35	0.34	0.37
657000	0.39	0.43	0.42	0.46	0.44	0.49
584000	0.73	0.80	0.77	0.84	0.82	0.90
511000	1.11	1.22	1.18	1.29	1.25	1.38
438000	1.73	1.91	1.83	2.02	1.95	2.15
365000	4.40	4.84	4.66	5.12	4.96	5.46
292000	4.48	4.93	4.74	5.21	5.05	5.55
219000	10.39	11.43	10.99	12.08	11.70	12.87
146000	11.05	12.15	11.68	12.85	12.44	13.69
73000	16.55	18.21	17.50	19.25	18.64	20.51
1200	236.5	324.6	250.1	343.2	266.4	365.6
1000	276.6	373.4	292.5	394.8	311.6	420.6
800	330.1	432.9	349.0	457.7	371.8	487.6
400	556.2	650.9	588.1	688.3	626.5	733.2
200	834.8	900.3	882.7	952.1	940.3	1014.1
160	863.4	978.0	913.1	1034.2	972.6	1101.6
80	1287.9	1352.7	1361.9	1430.5	1450.8	1523.8
40	1677.4	1670.4	1773.8	1766.3	1889.5	1881.5
30	1785.7	1790.0	1888.3	1892.9	2011.4	2016.4
20	1969.8	2017.8	2083.0	2133.8	2218.8	2272.9
15	2134.1	2162.4	2256.7	2286.7	2403.9	2435.8
10	2308.6	2346.6	2441.2	2481.5	2600.4	2643.3
5	2478.2	2492.0	2620.6	2635.2	2791.5	2807.1
4	2519.7	2495.1	2664.5	2638.5	2838.3	2810.5
2	3300.3	3080.9	3490.0	3258.0	3717.6	3470.5
1.5	3575.6	3301.7	3781.0	3491.4	4027.6	3719.1
1	3867.9	3583.0	4090.2	3788.9	4356.9	4036.0

	5		6		7	
Exceedance duration (hr)	Flow existing (cfs)	Flow prop. (cfs)	Flow existing (cfs)	Flow prop. (cfs)	Flow existing (cfs)	Flow prop. (cfs)
876000	0.11	0.12	0.01	0.01	0.02	0.02
803000	0.13	0.15	0.01	0.01	0.02	0.03
730000	0.28	0.31	0.02	0.02	0.05	0.05
657000	0.37	0.41	0.02	0.02	0.06	0.07
584000	0.68	0.75	0.04	0.05	0.12	0.13
511000	1.05	1.15	0.06	0.07	0.18	0.20
438000	1.63	1.80	0.10	0.11	0.28	0.31
365000	4.15	4.56	0.25	0.28	0.71	0.78
292000	4.22	4.64	0.26	0.28	0.72	0.79
219000	9.79	10.77	0.60	0.66	1.67	1.84
146000	10.41	11.45	0.63	0.70	1.78	1.96
73000	15.60	17.16	0.95	1.05	2.66	2.93
1200	222.9	305.9	13.6	18.7	38.1	52.2
1000	260.7	351.9	15.9	21.5	44.5	60.1
800	311.1	408.0	19.0	24.9	53.1	69.7
400	524.2	613.5	32.0	37.4	89.5	104.7
200	786.8	848.6	48.0	51.7	134.3	144.9
160	813.8	921.8	49.6	56.2	138.9	157.4
80	1213.9	1275.0	74.0	77.7	207.3	217.7
40	1581.0	1574.4	96.4	96.0	269.9	268.8
30	1683.0	1687.2	102.6	102.9	287.3	288.1
20	1856.6	1901.8	113.2	116.0	317.0	324.7
15	2011.4	2038.1	122.6	124.3	343.4	348.0
10	2175.9	2211.8	132.7	134.9	371.5	377.6
5	2335.8	2348.8	142.4	143.2	398.8	401.0
4	2374.9	2351.7	144.8	143.4	405.5	401.5
2	3110.6	2903.8	189.7	177.1	531.1	495.8
1.5	3370.1	3111.9	205.5	189.8	575.4	531.3
1	3645.6	3377.1	222.3	205.9	622.4	576.6

	9		11		14	
Exceedance duration (hr)	Flow existing (cfs)	Flow prop. (cfs)	Flow existing (cfs)	Flow prop. (cfs)	Flow existing (cfs)	Flow prop. (cfs)
876000	0.07	0.08	0.01	0.01	0.01	0.02
803000	0.09	0.10	0.01	0.01	0.02	0.02
730000	0.19	0.21	0.01	0.02	0.04	0.04
657000	0.25	0.27	0.02	0.02	0.05	0.05
584000	0.46	0.50	0.03	0.04	0.09	0.10
511000	0.70	0.77	0.05	0.06	0.14	0.15
438000	1.10	1.21	0.08	0.09	0.22	0.24
365000	2.78	3.06	0.20	0.22	0.56	0.61
292000	2.83	3.12	0.21	0.23	0.57	0.62
219000	6.57	7.22	0.48	0.53	1.31	1.44
146000	6.98	7.68	0.51	0.56	1.40	1.54
73000	10.46	11.51	0.76	0.84	2.09	2.30
1200	149.5	205.2	10.9	14.9	29.9	41.0
1000	174.9	236.0	12.7	17.2	35.0	47.2

800	208.7	273.6	15.2	19.9	41.7	54.7
400	351.6	411.5	25.6	29.9	70.3	82.3
200	527.7	569.2	38.4	41.4	105.5	113.8
160	545.8	618.3	39.7	45.0	109.2	123.7
80	814.2	855.2	59.2	62.2	162.8	171.0
40	1060.4	1056.0	77.1	76.8	212.1	211.2
30	1128.9	1131.6	82.1	82.3	225.8	226.3
20	1245.3	1275.6	90.6	92.8	249.1	255.1
15	1349.1	1367.0	98.1	99.4	269.8	273.4
10	1459.4	1483.5	106.1	107.9	291.9	296.7
5	1566.7	1575.4	113.9	114.6	313.3	315.1
4	1592.9	1577.3	115.8	114.7	318.6	315.5
2	2086.4	1947.7	151.7	141.7	417.3	389.5
1.5	2260.4	2087.3	164.4	151.8	452.1	417.5
1	2445.2	2265.1	177.8	164.7	489.0	453.0

3.3 HYDRAULICS

An analysis of channel hydraulics was conducted at each of the eight geomorphic index points (see Figure 3.1). Rating curve relationships for stage versus discharge (cfs), average velocity (fps), and average shear stress (lbf/ft^2) were generated at each index point for base flow through the 100-year event flow conditions. All calculations were made using HydroCalc©, a one dimensional model for calculating hydraulic parameters in uniform, open-channel flow conditions (Molls, 2008). The purpose of the hydraulic analysis is to characterize hydraulic conditions at geomorphic index points for a range of flow conditions and to develop information needed for the shear stress index calculations in the next section.

3.3.1 Hydraulic Parameter Development

Baseline data required to perform the hydraulic calculations were channel geometry, slope, and channel roughness. Geometry and slope data were obtained from survey and topographic information collected for this study (see Section 2.5.1) whereas channel roughness (Manning's *n*) was estimated from field inspection observations using standard practices. A single *n*-value representative of average roughness for the cross-section over a range of flows was used for each index point. Table 3.5 summarizes the channel slope and Manning's *n* values developed for each geomorphic index point.

Table 3.5 Channel Slope and Roughness Parameters for Geomorphic Index Points

Geomorphic Index Point	Slope ft/ft	Manning's *n*
ECORP-2	0.009	0.045
Stagegage	0.009	0.045
Point 5	0.004	0.035
Point 6	0.009	0.045
Point 7	0.011	0.035

Point 9	0.010	0.035
Point 11	0.002	0.035
Point 14	0.006	0.035

3.3.2 Results

Rating curves developed for the hydraulic analysis are provided in Appendix 2. The rating curves are for discharge versus stage, normal velocity versus stage, and average shear stress versus stage. Note that peak discharges for the 2-yr, 5-yr, 10-yr, and 100-yr storm events are shown on each rating curve. These data were obtained from peak flows at Prairie City Road (Domenichelli & Associates, 2007), scaled to the basin area of each index point. Table 3.6 summarizes peak discharge values at each geomorphic index point.

Table 3.6 Peak Discharges for 2, 5, 10, and 100-year events at Geomorphic Index Points

Geomorphic Index Point	Subwatershed area (acres)	Scaled 2-yr Peak Discharge (cfs)	Scaled 5-yr Peak Discharge (cfs)	Scaled 10-y Peak Discharge (cfs)	Scaled 100-yr Peak Discharge (cfs)
ECORP-2	5888	1116	1737	2161	3620
Stagegage	6272	1189	1850	2302	3856
Point 5	5248	995	1548	1926	3227
Point 6	320	61	94	117	197
Point 7	896	170	264	329	551
Point 9	3520	667	1038	1292	2164
Point 11	410	78	121	150	252
Point 14	850	161	251	312	523

Many of the index points exhibit a well defined channel cross-section with steep banks that abruptly transitions into a wide floodplain or other significant change in bank slope, such as index points 6, 14, and ECORP-2 (see Appendix 1 – Cross-Sections). These cross-section characteristics significantly affect the average velocity and shear stress rating curves, causing both to decrease when flows overtop the defined channel. This can be observed at index points ECORP-2 and 6 (see Figure A2.28, A2.29, A2.34 and A2.35 in Appendix 2). Although the average velocity and shear stress declines with stage as flows overtop the channel, the localized shear stress and velocity in the bankfull channel at these sites would most likely show a steady increase with stage. In contrast, index points 5, 7, 9, 11 and Stagegage exhibit less abrupt changes in slope from the defined channel bank onto the floodplain. Consequently, these sections show steady increases in average velocity and shear stress with increasing stage.

3.4 SHEAR STRESS INDEX

To assess the susceptibility of channels within the Alder Creek watershed to induced channel instability due to changed hydrologic conditions, **nhc** completed a hydromodification assessment of changes in applied and excess channel shear stress for the full range of stream discharge, from commonly occurring low base flow conditions, through annual and intra-annual moderate storm flow events, to extreme and rare flood events. A “shear stress index” which is a measure of the applied channel shear for any given discharge is computed and compared for both existing and modified hydrologic conditions resulting from watershed land use changes. The approach utilized herein is similar to the approach utilized by the King County, Santa Clara Valley Water District, Contra Costa County, and other stormwater management agencies (Hartley and Funke, 2001; Rohrer and Roesner, 2005; SCVURPPP, 2005). A similar approach was recently completed by Geosyntec Consultants in their watershed management study of the Laguna Creek watershed, located adjacent and to the southwest of Alder Creek, and completed in July of 2007. The shear stress index developed for the Alder Creek watershed study and described in the following section integrates the cumulative distribution of excess shear stress greater than the point of incipient motion[1] over the entire range of hydrologic conditions. This index is computed for several geomorphic index locations within the watershed; specifically index points 5, 6, 7, 9, 11, 14, ECORP-2, and Stagegage (see Figure 3.1). Data required for the analysis are the flow duration characteristics of the watershed hydrology, hydraulic variables at each geomorphic index point, and bed material particle size distribution data described and presented in previous sections.

3.4.1 Methodology

The shear index combines flow duration characteristics with a shear stress function to compute the non-dimensional shear stress index as a measure of the potential for a given flowrate to move sediment. Flow duration curves were developed and described in detail in section 3.2 and provided in Appendix 2 for each index point. Rating curves for discharge, velocity, and shear stress are described in detail in section 3.3 and provided in Appendix 2 for each index point.

Shear Stress Index Development

To calculate the shear stress index *S*, the excess shear stress exerted on particles in the stream is integrated over time. The solved integral shear stress function is described as follows:

$$\boldsymbol{S} = (\tau_o - \tau_c)t/(\gamma_s - \gamma_w)D_{50}$$

where

S	=	Shear stress index (unitless)
τ_o	=	Average Shear Stress (lbf/sq. ft)
τ_c	=	Critical Shear Stress (lbf/sq. ft)
t	=	Decimal % time a discharge is greater than or equal to a given value
γ_s	=	Specific weight of rock (165 lbf/ft^3)
γ_w	=	Specific weight of water (62.4 lbf/ft^3)
D_{50}	=	Particle size where 50 percent of the bed mixture is finer (ft)

Critical shear stress (lbf/sq. ft) was developed for each index point using the methodology described in U.S. Army Corps of Engineers (1994) Engineer Manual 1110-2-1418. A dimensionless Shield's parameter of 0.06 was used to calculate the critical shear stress for

[1] The point of incipient motion of a particle is the critical condition between transport and no transport. The force acting on a particle in the direction of flow is a shear force which is due to a shear stress τ_o (lbf/sq. ft). The shear stress associated with the point of incipient motion is the critical shear stress $\tau_c = \tau_o$ (lbf/sq. ft).

each of the index points (see Table 1). Using U.S. Army Corps of Engineers (1994) guidance, a particle size of D_{50} was selected to be the representative size for bed material. The D_{50} for index points 5, 6, 7, 9, Stagegage, and ECORP-2 are derived form the particle size distribution curves presented in Appendix 1. Particle sizes were too small to conduct a Wolman Count at index point 11 and the D_{50} size was estimated visually to be 10 mm . A D_{50} size at index point 14 was not obtained due to access limitations and was assumed to be the same as that of index point 11. The D_{50} and τ_c for each index point are summarized in Table 3.7, as are critical velocity and critical discharge.

Table 3.7 D_{50} Particle Sizes and Critical Parameters used in Shear Index Calculations

Geomorphic Index Point	D_{50} (mm)	Critical Shear Stress (lbf/sq. ft)	Critical Velocity (fps)	Critical Discharge (cfs)
Stagegage	35	0.7	4	176
ECORP-2	40	0.8	4	228
5	43	0.9	6*	4000*
6	19	0.4	4	51
7	36	0.7	5	259
9	50	1	6	321
11	10	0.2	2*	200*
14	10	0.2	2	30

*Number associated with the largest value calculated for the flow range tested. The actual value is greater than the value shown

Velocity and shear stress duration curves were developed to show the distribution of velocities and shear stresses in comparison to the exceedance probability of occurrence. Critical discharge, velocity, and shear stress values are shown in each curve to identify the distribution of values affecting the shear stress index (see Figures A2.1-A2.24 in Appendix 2).

Shear Stress Index Ratio

The relative change in excess shear stress for proposed versus existing conditions is evaluated by a shear stress index ratio (R_s). The shear stress index ratio is the ratio between the proposed condition and existing condition cumulative integrated shear index function ($R_s = \Sigma S_{prop}/\Sigma S_{Exist}$). The shear stress index ratio thus provides a non-dimensional measure of the changes in total shear stress applied over the entire range of discharges for both existing and modified watershed conditions.

3.4.2 Results

Based on the methodology described above, shear stress index curves and shear stress index ratios were developed at each geomorphic index point. Table 2 shows the shear stress index ratios and the percent increase from existing to proposed conditions at each index point. Figure 3.5 is an example of the shear stress index curve at index point

Stagegage. Shear stress index curves for all of the geomorphic index points are located in Appendix 2 (Figures A2.48-A2.55).

Table 3.8 Shear Stress Index Results

Geomorphic Index Point	Shear Stress Index Ratio	% Increase
Stagegage	1.27	27%
ECORP-2	1.30	30%
5	**	**
6	1.61	61%
7	1.01	1%
9	1.22	22%
11	**	**
14	1.58	58%

**At these geomorphic index points there is no excess shear stress for any of flows within the range tested in this study

At index points 5 and 11 in Table 3.8, the actual average shear stress is lower than the critical shear stress for every flow that was tested in this study. Figures A2.9 and A2.24 in Appendix 2 show the critical shear stress plotted with shear duration curves for each of these locations.

3.4.3 Discussion

Figure 3.5 shows a sample shear stress index curve for index point "Stagegage". The maximum shear stress exerted at this point is during discharges between 200 and 900 cfs for existing conditions and 150 and 1000 cfs for proposed conditions. The net increase of excess shear stress exerted on the channel bed material for proposed versus existing conditions yields a shear stress index ratio of R_s=1.27. This means that there is a 27% increase in the excess shear stress under proposed conditions that may cause an increase in erosion at the Stagegage cross section. Shear stress ratios that are equal to or close to 1 indicate that there is no significant increase in excess shear stress at a given cross section.

In contrast, index points 5 and 11 are very mildly sloped sections in the drainage. Since applied average shear stress is a function of slope, the average shear stress is lower in these sections. In this case, the average shear stress was always lower than the critical shear stress because of the mild slopes of these sections and no shear index was calculated.

3.5 GEOMORPHIC IMPACTS OF HYDROMODIFICATION

Results of the shear stress index analysis show that average shear stress exerted on the channel perimeter will increase by 1% to 61% from existing to proposed conditions at the geomorphic index points. This indicates that the potential for erosion and channel instability will increase. Empirical studies in the San Francisco bay area showed that channel instability occurred in 50% of streams where the work index, determined by sediment transport equations, exceeded 1.6 (SCVURPPP, 2005). They concluded that an index ratio higher than 1.2 indicated the potential for channel instability. Based on this, shear stress index results in Table 3.8 indicate the potential for future channel instability under the proposed hydrologic conditions at 5 of the 8 geomorphic index points.

Geomorphic index points 5 and 11 exhibit an inability of flows to transport bed material D50 sizes (see Table 3.8). Consequently, no comparison of erosion potential can be made between existing and proposed hydrologic conditions. Low average shear stresses in these areas are mainly due to very shallow stream gradients caused by downstream bedrock control. Due to these constraints, any channel instability resulting from hydromodification in these areas would be restricted to bank erosion or stream avulsion.

Widespread near surface bedrock is an important constraint on channel adjustment in the Alder Creek watershed. Bedrock outcrops are very common throughout the stream network. Consequently, bank erosion, at locations where bedrock is not present on the stream banks is the expected stream response to channel instability whereas bed erosion and stream incision are expected to be more limited.

It is important to note that hydromodification has already occurred in the Alder Creek watershed north of Highway 50 and that streams draining this area show no channel instability at their confluence with Alder Creek (see photos of Site 6, 7, and 8 in Appendix 1). Runoff generated from this developed area passes through a series of retention ponds designed to reduce peak flows to pre-developed rates as required by the City of Folsom. Although a hydromodification analysis of pre-development versus post-development hydrologic conditions was not conducted for this area, it appears that whatever increased runoff volume exists is not adversely affecting channel stability at the field inspection sites examined for this study (see Figure 2.6).

4. WATERSHED MANAGEMENT RECOMMENDATIONS

4.1 GENERAL CONSIDERATIONS

Watershed management recommendations should be developed in accordance with the existing topographic, geomorphic, hydrologic, and climatic characteristics of the watershed. General hydrologic and land management practices such as minimizing encroachments into floodplains, eliminating or minimizing any in-channel encroachment or channel modification, providing for hydrologic and sediment transport through any bridge crossings by utilizing open span structures, minimizing or mitigating for any hydrologic response changes through detention or retention storage, providing for infiltration of stormwater flows, and utilizing at grade detention outlet facilities are all state of the practice procedures that can be incorporated into facility design for proposed land use changes. Site specific design considerations such as use of bioengineered bank or erosion protection measures, stabilization and fluvial process enhancement of existing channel instabilities, and siting and sizing infiltration swales, detention basins, or water quality improvement basins should all be considered during the development of proposed land use changes within the Alder Creek watershed. Detailed descriptions, concept drawings and project design features for these and other Best Management Practices (BMPs) are available from several sources including the California Stormwater Quality Association Best Management Practice Handbooks (CASQA, 2003), State Water Resources Control Board (2007), California State Department of Transportation (2007), and others (EPA, 2008; DWR, 2008).

A list of relevant BMP guidance applicable to the Alder Creek watershed was compiled from the above standard and state of the art practice documents and is presented in Section 4.2. These recommendations provide general guidance for future watershed development and management in the Alder Creek basin with respect to basin hydrology and channel stability and can most easily be applied during the planning and design phase of new construction. Recommended BMPs pertaining to biologic and ecologic conditions in the watershed and to local stakeholder concerns are provided in a separate report by Edaw, Inc. The development of specific BMP design drawings for stormwater facilities in the proposed Easton and SOI development plans is beyond the scope of this study. Rather, this study focuses on BMP guidance recommendations that are standard and state of the art practice and should be considered and incorporated where appropriate into the planning and design process for new development in the Alder Creek watershed.

4.2 RECOMMENDATIONS

Site specific recommendations for minimizing hydrologic and geomorphic impacts to the Alder Creek watershed and riparian corridor include the following standard practice features such as:

- Detention and retention basins – for both minimizing peak flow changes, as well as minimizing changes to flow duration characteristics
- Infiltration swale grading – incorporate on site infiltration swales to encourage groundwater recharge, provide for establishment of mitigation wetland sites if necessary, and to minimize stormwater discharge to established watercourses
- Low impact development – minimize hardscape and impermeable surface modifications to the watershed to the extent possible
- Bioengineered stream stabilization – utilize vegetative and rock stabilization features that provide for enhancement of riparian habitat and maintenance of natural hydrologic and channel to floodplain interactions
- At grade outfall design – minimize slope differences between any stormwater or detention facility outfall confluence channel with the existing receiving channel gradient
- Channel and floodplain setbacks – minimize any encroachment into stream channels, and limit grading and site modifications with in the 200-year floodplain boundaries to passive activities such as greenbelt preserves for wildlife habitat and recreation corridors.
- Bridge and culvert openings – minimize to the extent possible bridge embankment encroachments into the channel and floodplain corridor; utilize open bottom box culverts to allow sediment passage on smaller drainage courses

Integration of these recommendations with the results of stakeholder meetings and EDAW's technical study are anticipated next steps for the development of prioritized, integrated BMP approaches and guidance for future construction and post-construction (municipal stewardship) activities in the Alder Creek stream network.

5. SUMMARY AND CONCLUSIONS

The geomorphic and hydrologic analysis completed for the Alder Creek Watershed study indicates that shallow soils, prevalence of exposed bedrock on the stream bed and banks, and the now filled with sediment Natoma Company Dam profoundly influence the hydrologic regime and limits the susceptibility to channel instability within much of the presently undeveloped watershed. In spite of the apparent resilience and resistance of the watershed's riparian corridors to limited morphological change due to the proposed watershed development, site specific design considerations such as those described above should be considered in the design of any proposed land use changes within the watershed. These recommendations are generally easily accommodated by minimizing encroachments into riparian and floodplain corridors and minimizing grading and changes to surface permeability characteristics of the watershed.

5.1 STUDY LIMITATIONS

The primary limitation in this study is the lack of hydrologic data. The watershed is presently ungaged and no historical flow or precipitation gage data are available, nor has a continuous simulation model been developed based on regional data. Ideally, flow duration curves are developed from continuous flow data over a long-duration period of record or from continuous simulation model results. Flow duration curves in this study were developed from 24-hour storm event hydrographs and monthly averaged flow data. These results are considered preliminary and useful for screening purposes given that identical approaches were used in the development of flow duration curves for pre- and post-project hydrologic conditions.

The shear stress index method used in this study is not a direct measure of instream erosion and uses representative, averaged values to represent a range of shear stress conditions. It provides an approximate estimate of real change that is most useful when making relative comparisons between pre- and post-project hydrologic conditions to identify likely trends.

A peak flow of 1,460 cfs were measured by E-Corp at the stagegage index point during a storm on January 4th, 2008. We noted during our February, 2008 field inspection that bed material in the majority of some areas was covered with algae and had not moved during the storm event; however, the critical flow velocity at stagegage is estimated to be 221 cfs (see fig. A2.1 in Appendix 2). These types of variations in bed material size, imbrication, and local hydraulic conditions that locally affect critical shear stress were not accounted for in the shear stress index approach completed for this study.

Additional limitations in this study include an assessment of sediment supply changes following land development, impacts of detention and retention basins on the post-project flow duration curves, and the effects of nuisance flows on instream vegetation and consequent impacts on bed and bank erosion rates. These items are discussed further in the recommendations section.

5.2 RECOMMENDATIONS FOR FUTURE WORK

Recommendations for future work largely stem from the limitations outlined above. The results of this study indicate the potential for higher instream erosion and an increase in the likelihood of channel instability at 5 of 8 geomorphic index points under proposed conditions. As a result, we recommend that refinements be made to the hydromodification analysis in order to provide specific recommendations for hydromodification mitigation. First, a regional analysis should be conducted to develop a continuous simulation hydrologic model of the Alder Creek basin. Proposed hydromodification mitigation design alternatives (such as detention basins) can then be introduced into the model to assess effects on flow duration curves for existing and proposed conditions.

Following these improvements to the flow duration curves, additional refinements to the hydromodification analysis can be conducted. These include the calculation of applied and critical shear stress for in-channel and floodplain areas that account for changes in hydraulic conditions, bed and bank material, and vegetation along the banks and on the floodplain. The number of geomorphic index points in the watershed could be expanded, particularly in the upper watershed where access was limited to one site for this study. Lastly, incorporation of the expected decrease in sediment supply between existing and proposed conditions could be implemented into the shear stress index ratio method.

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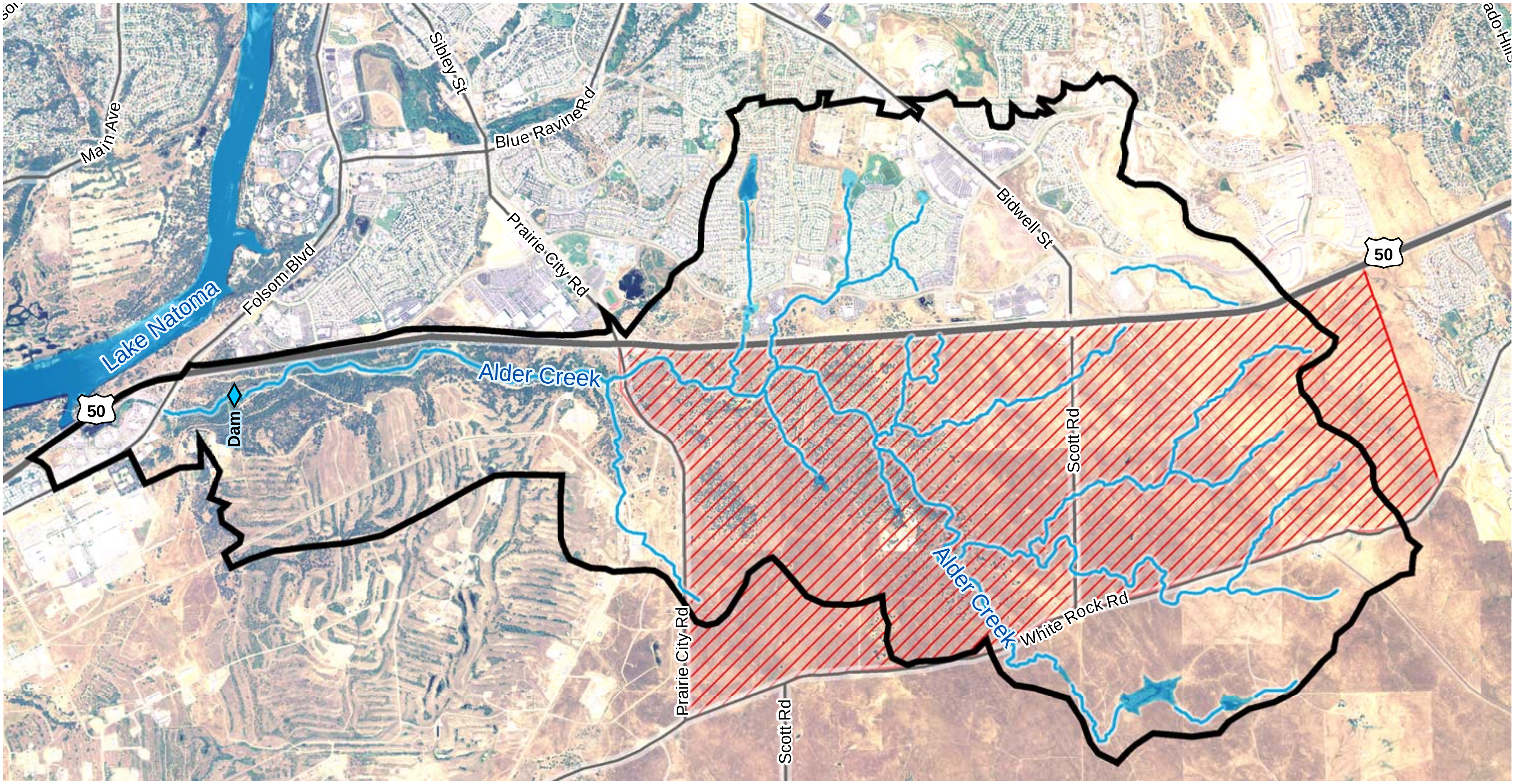


Data Sources: NAIP Color Orthoimagery, 2005. ESRI Roads, Counties, Cities, and Ponds, 2008.

Legend

- Road
- Stream
- Pond or Reservoir
- Watershed Boundary
- City of Folsom Sphere of Influence
- Dam

County Reference Map

Alder Creek Watershed Assessment

Study Area Map

Scale - 1:48,000 1 inch = 4,000 feet

0 2,000 4,000 8,000 Feet

CA State Plane, Zone II	horz. datum: NAD 83	horz. units: feet
northwest hydraulic consultants	project no. 50464	July 2008

Figure 1.1 - Study Area Map

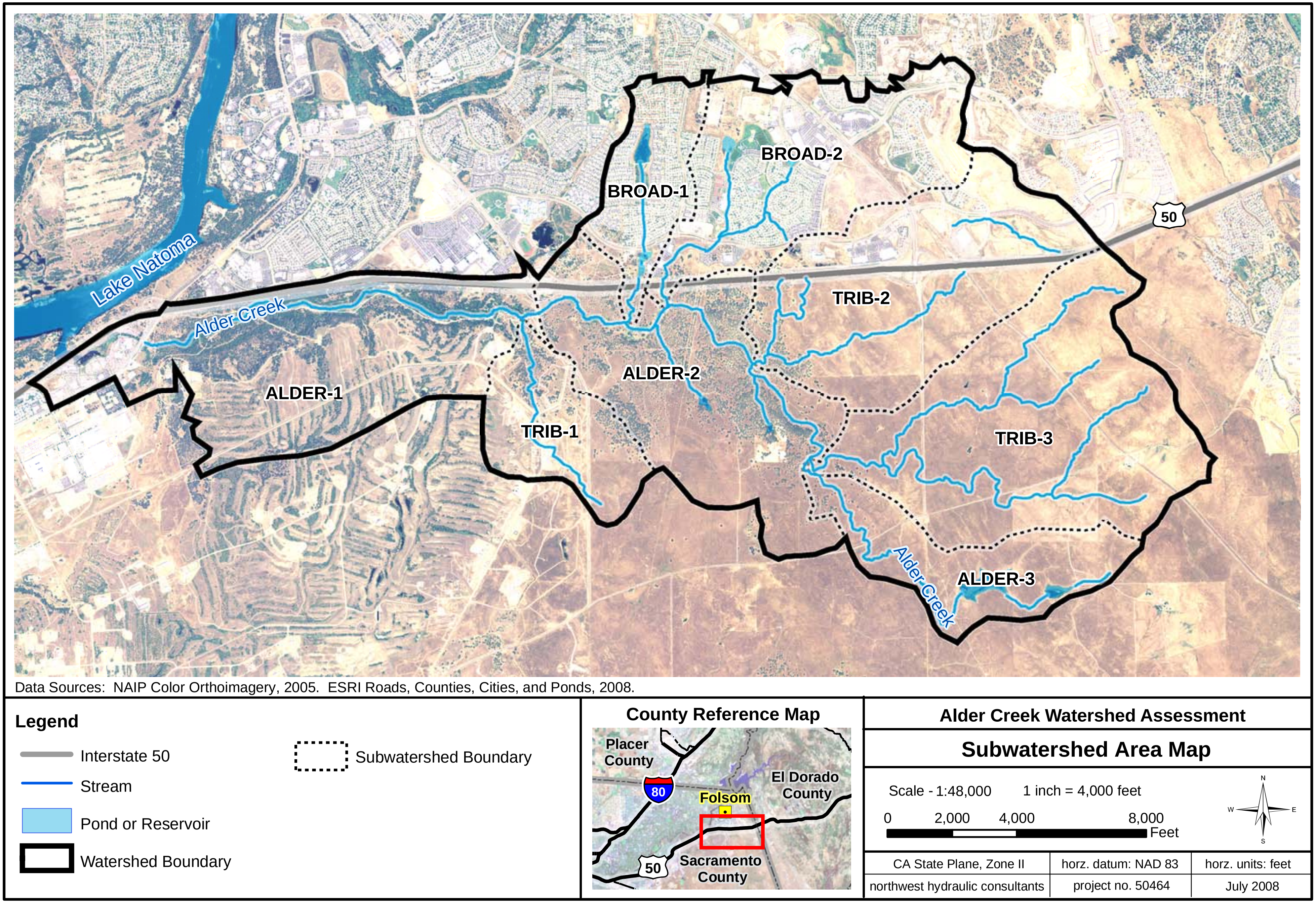


Figure 2.2 - Subwatershed Area Map

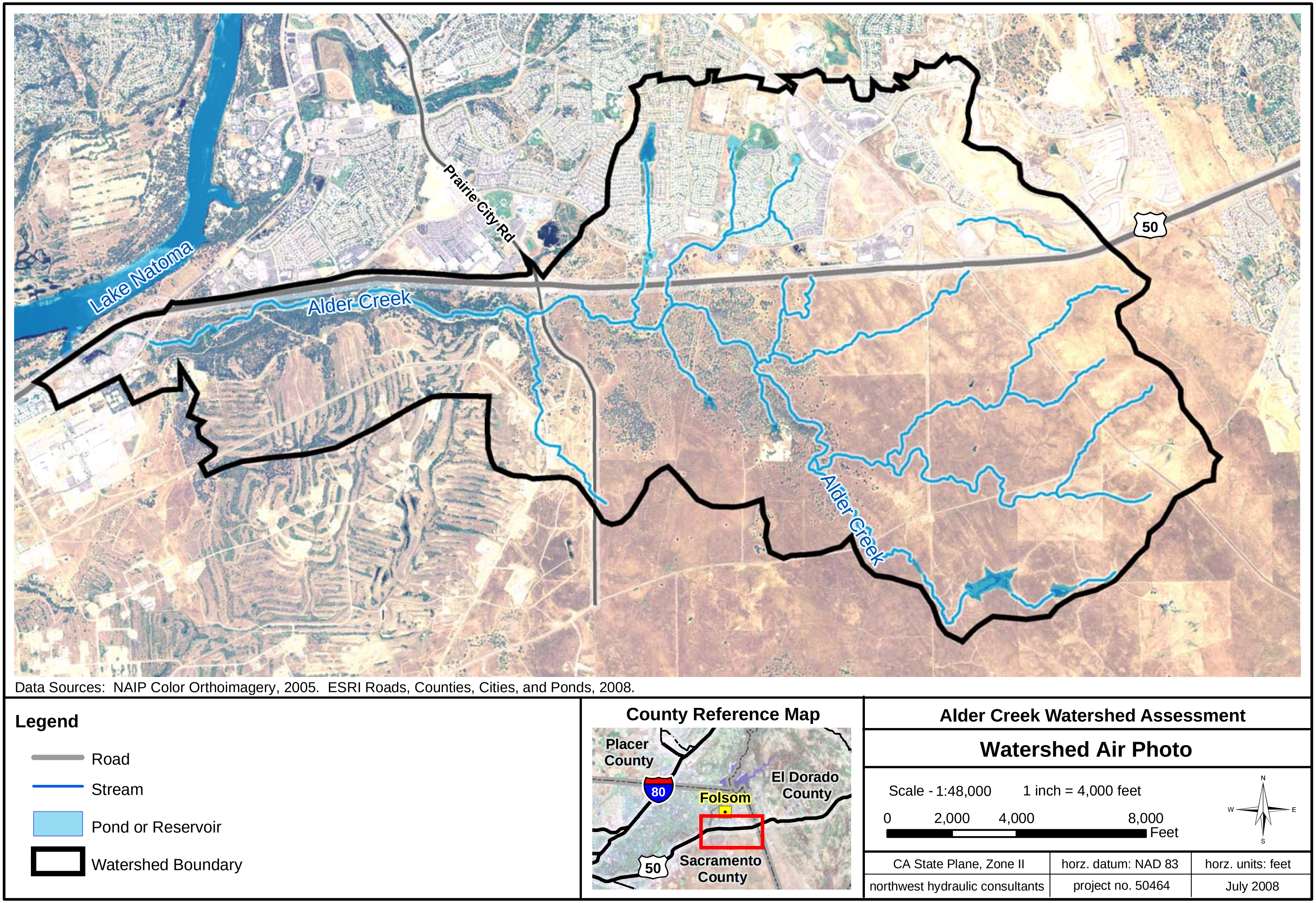


Figure 2.3 - Watershed Air Photo

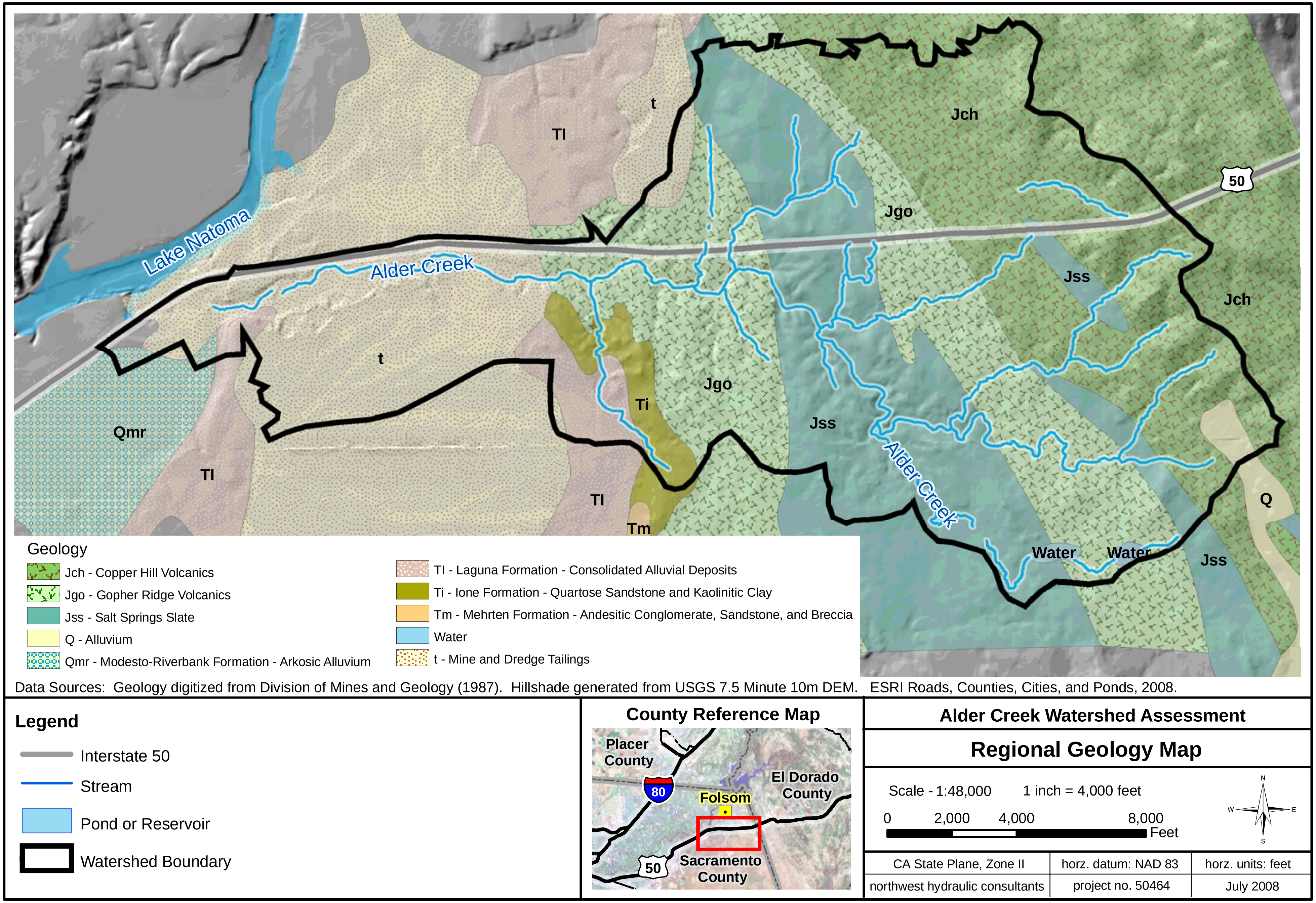


Figure 2.4 - Regional Geology Map

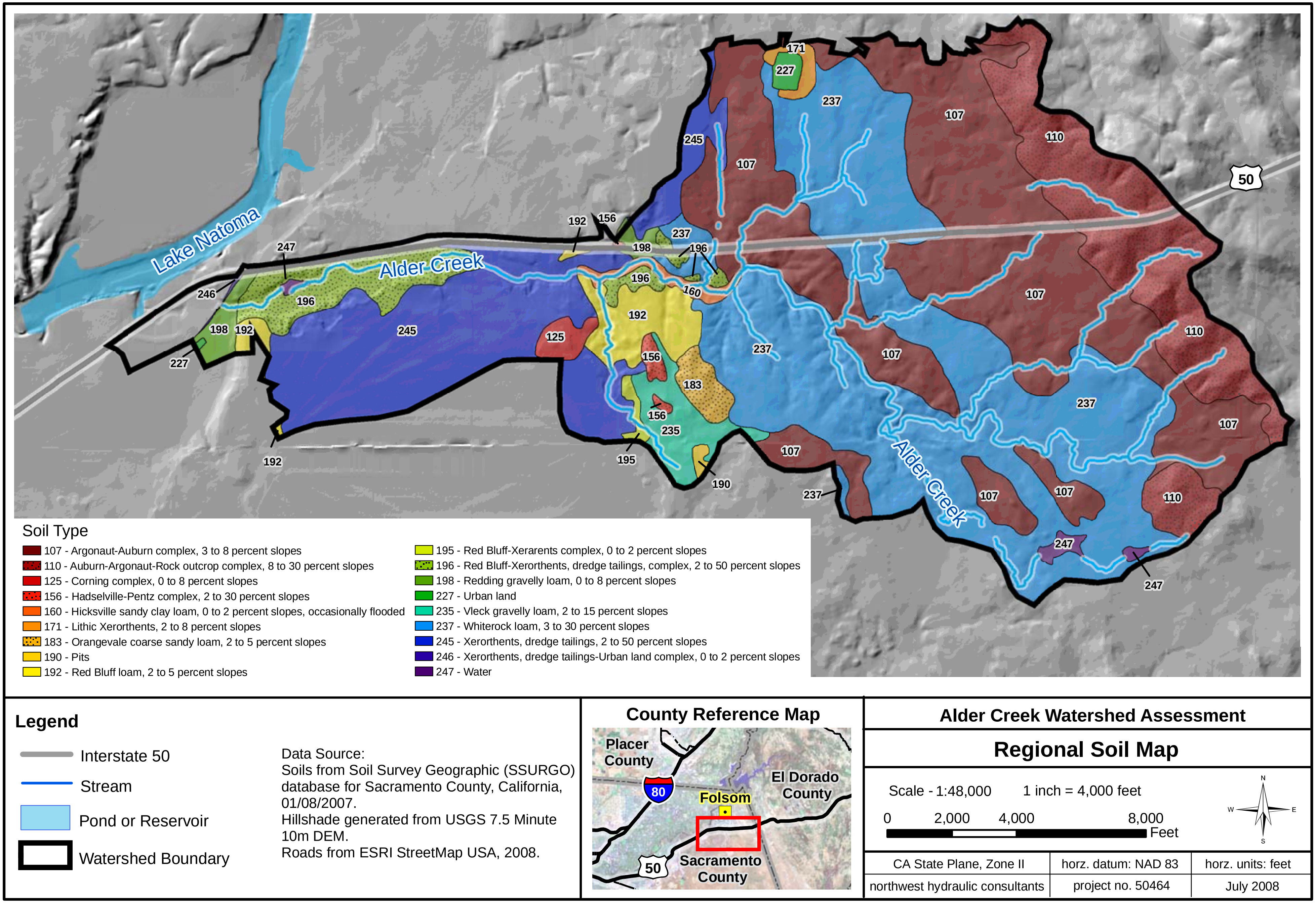
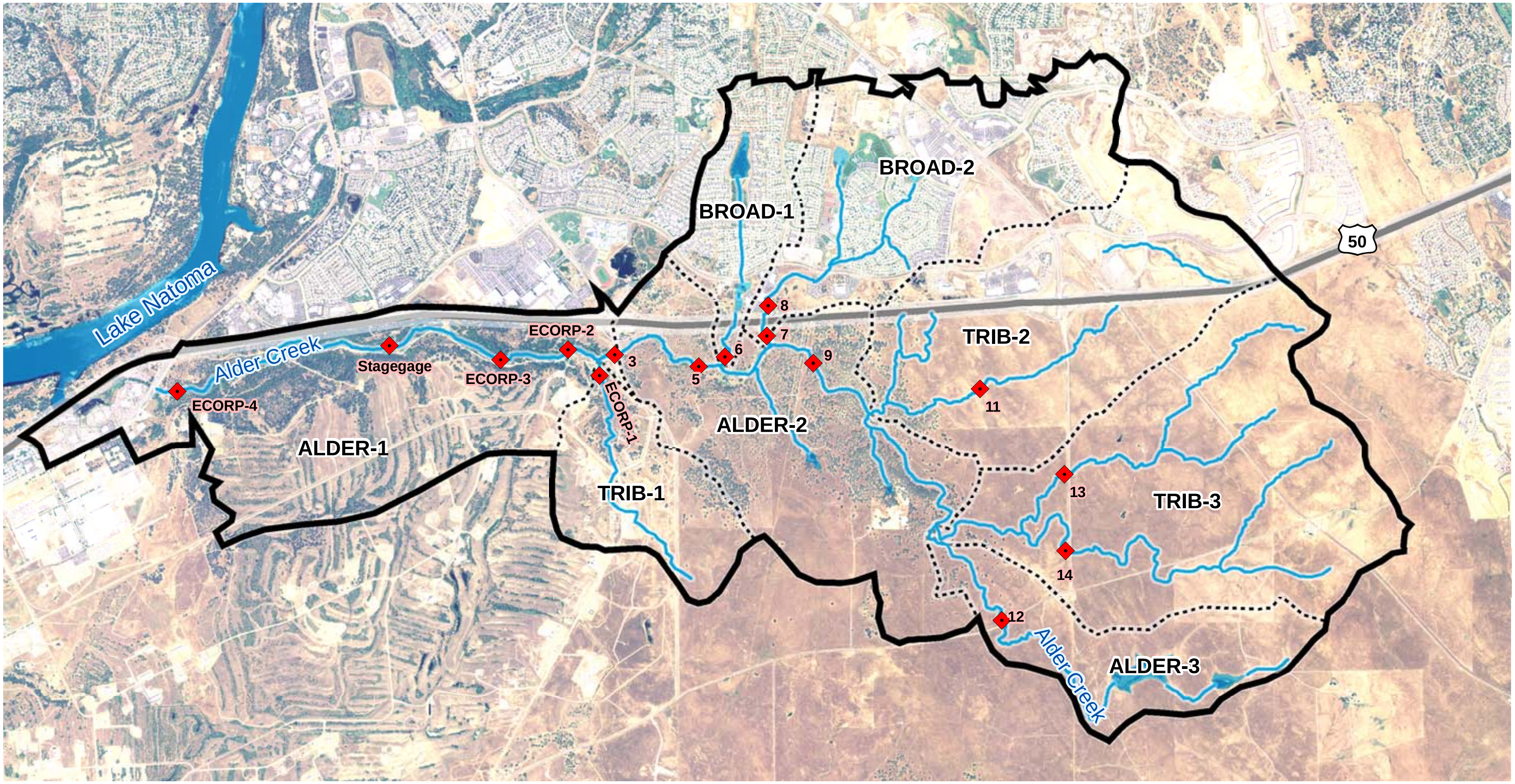


Figure 2.5 - Regional Soil Map



Data Sources: NAIP Color Orthoimagery, 2005. ESRI Roads, Counties, Cities, and Ponds, 2008.

Legend

- Interstate 50
- Stream
- Pond or Reservoir
- Watershed Boundary
- Subwatershed Boundary
- Field Inspection Site

County Reference Map

Alder Creek Watershed Assessment

Field Inspection Sites

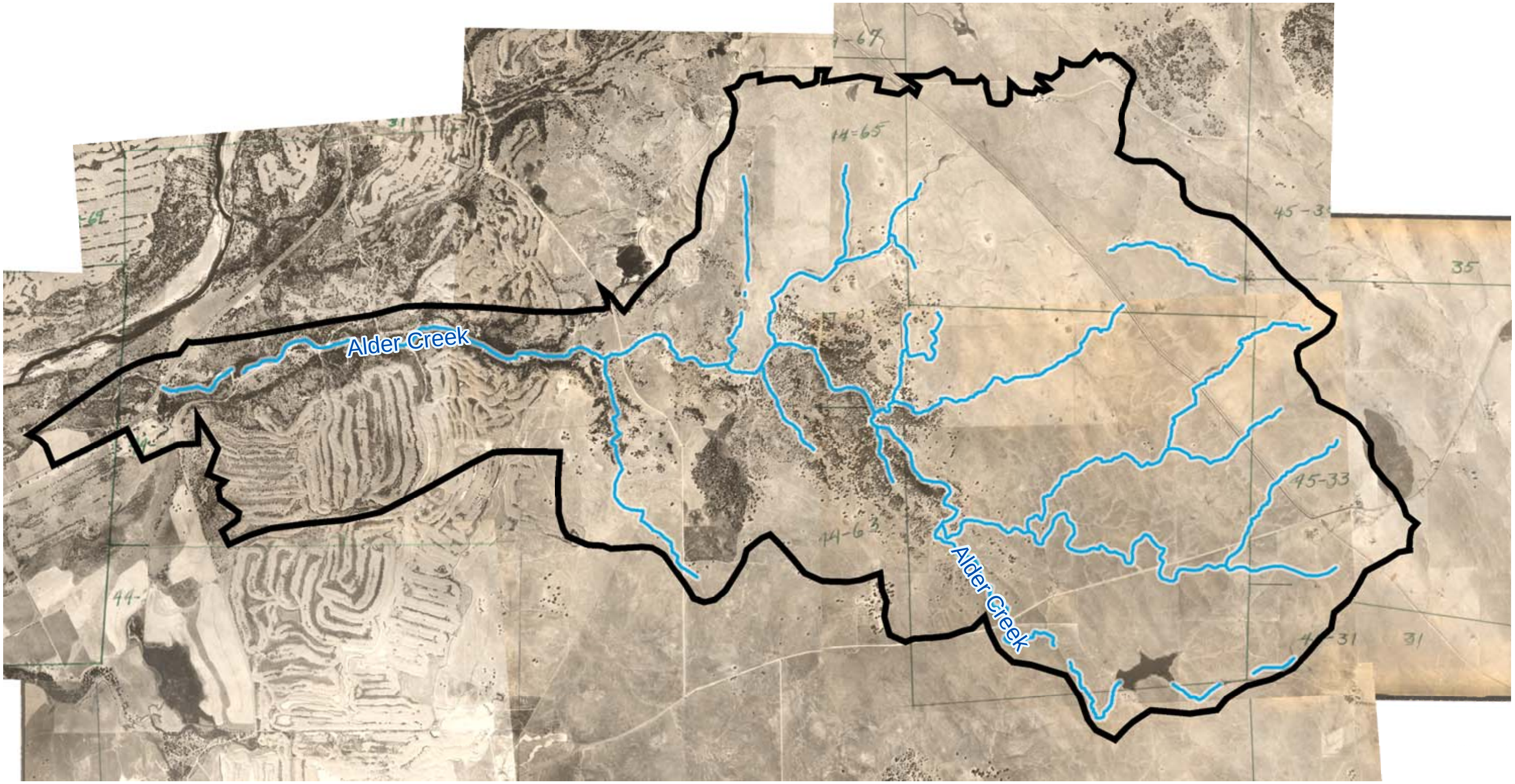
Scale - 1:48,000 1 inch = 4,000 feet

0 2,000 4,000 8,000 Feet

N E S W

CA State Plane, Zone II	horz. datum: NAD 83	horz. units: feet
northwest hydraulic consultants	project no. 50464	July 2008

Figure 2.6 - Field Inspection Sites



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Legend

- Stream
- Watershed Boundary

County Reference Map

Alder Creek Watershed Assessment

1937 Air Photo

Scale - 1:48,000 1 inch = 4,000 feet

0 2,000 4,000 8,000 Feet

CA State Plane, Zone II	horz. datum: NAD 83	horz. units: feet
northwest hydraulic consultants	project no. 50464	July 2008

Figure 2.7 - 1937 Air Photo

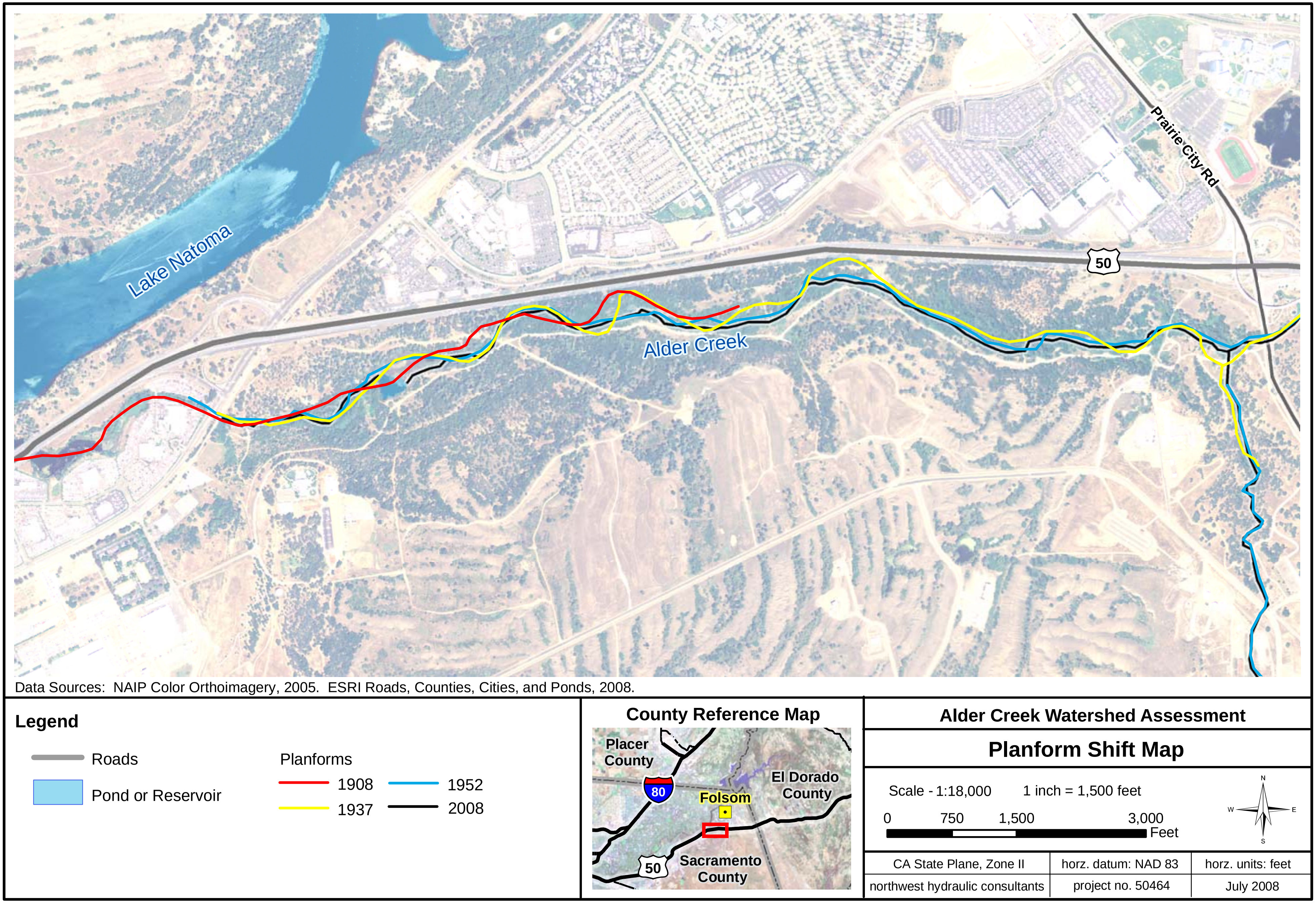


Figure 2.8 - Planform Shift Map

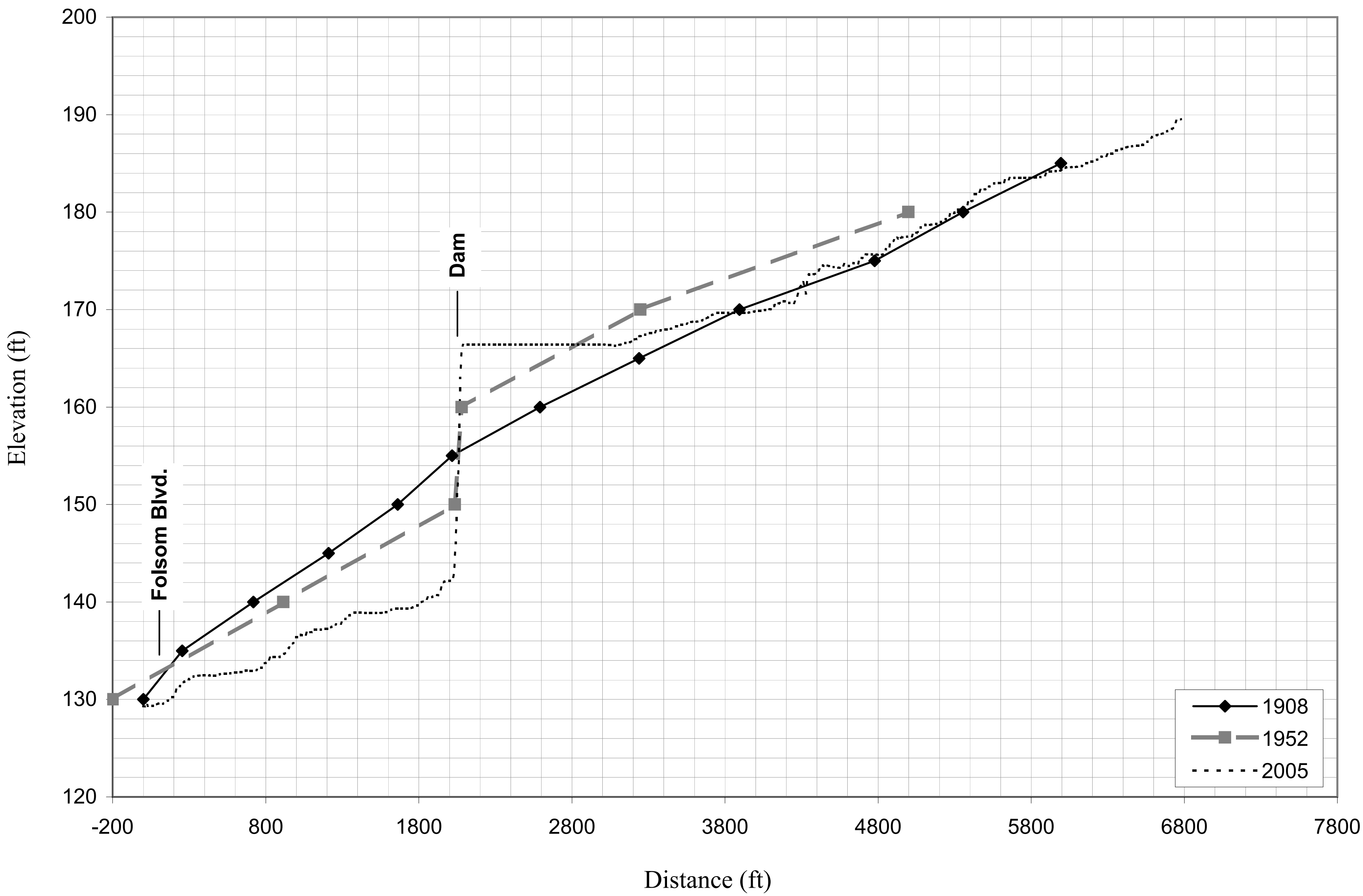


Figure 2.9 Historical longitudinal profiles of lower Alder Creek

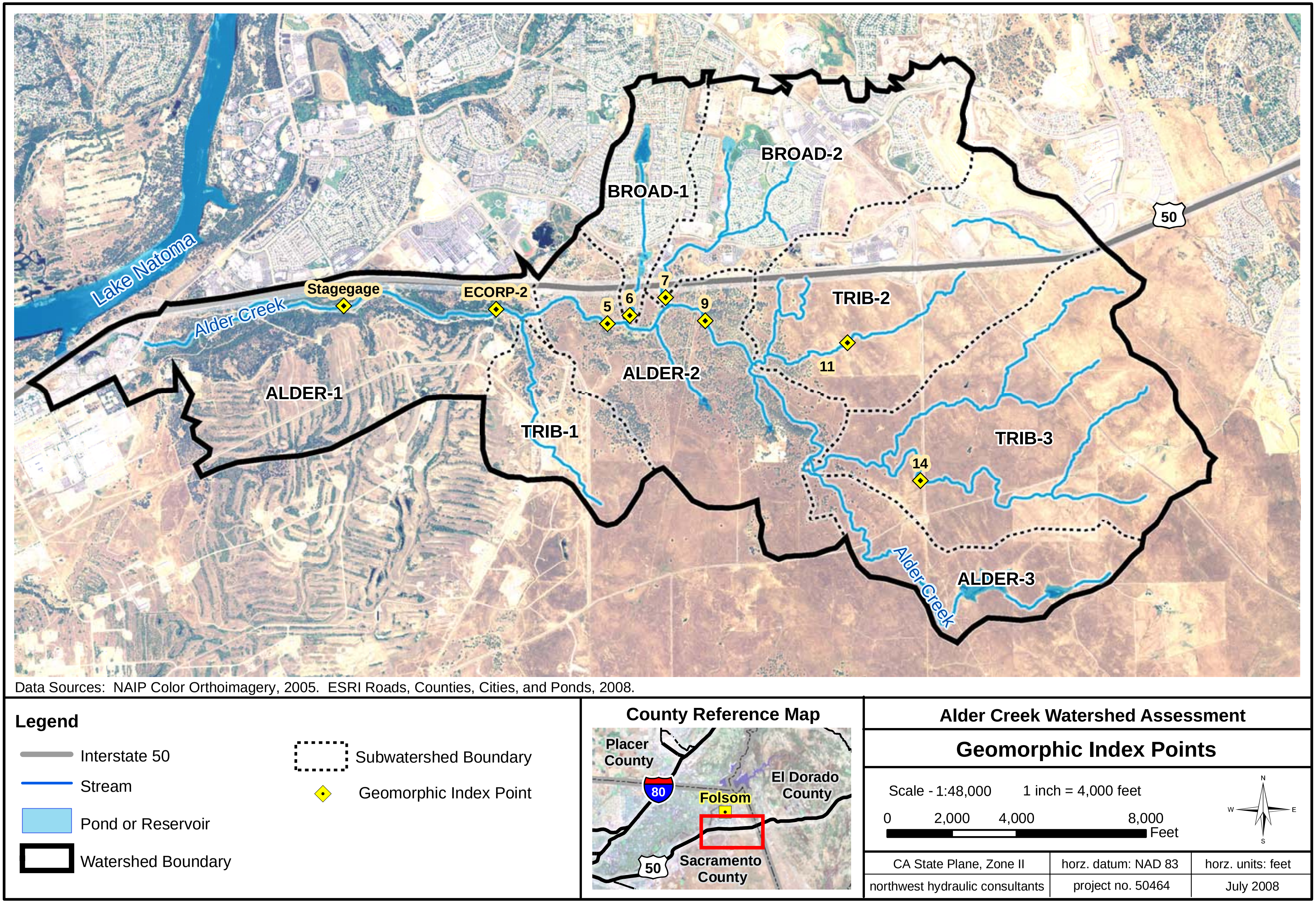


Figure 3.1 - Geomorphic Index Points

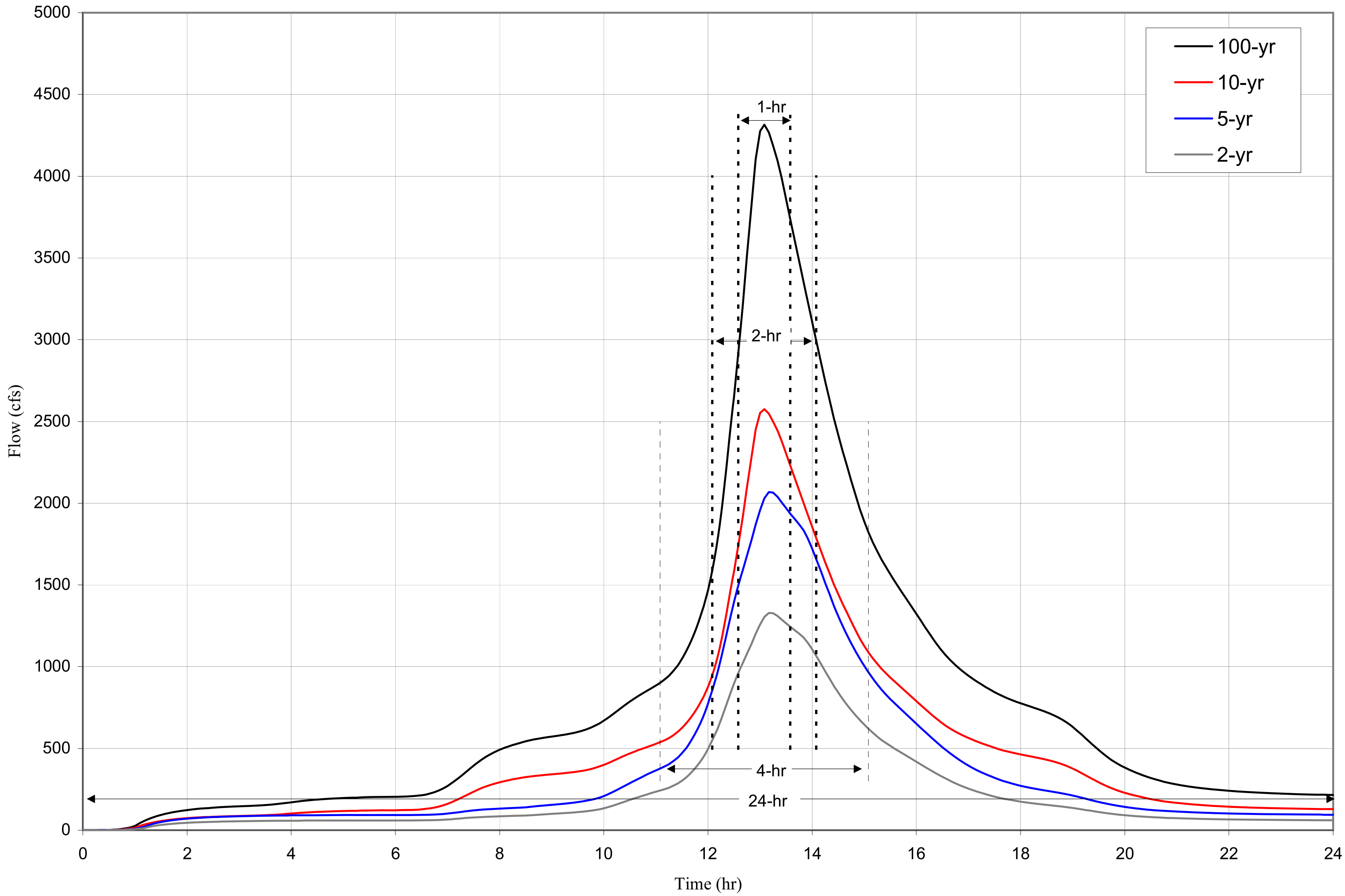


Figure 3.2 Flood Hydrographs at Prairie City Road for Existing Conditions

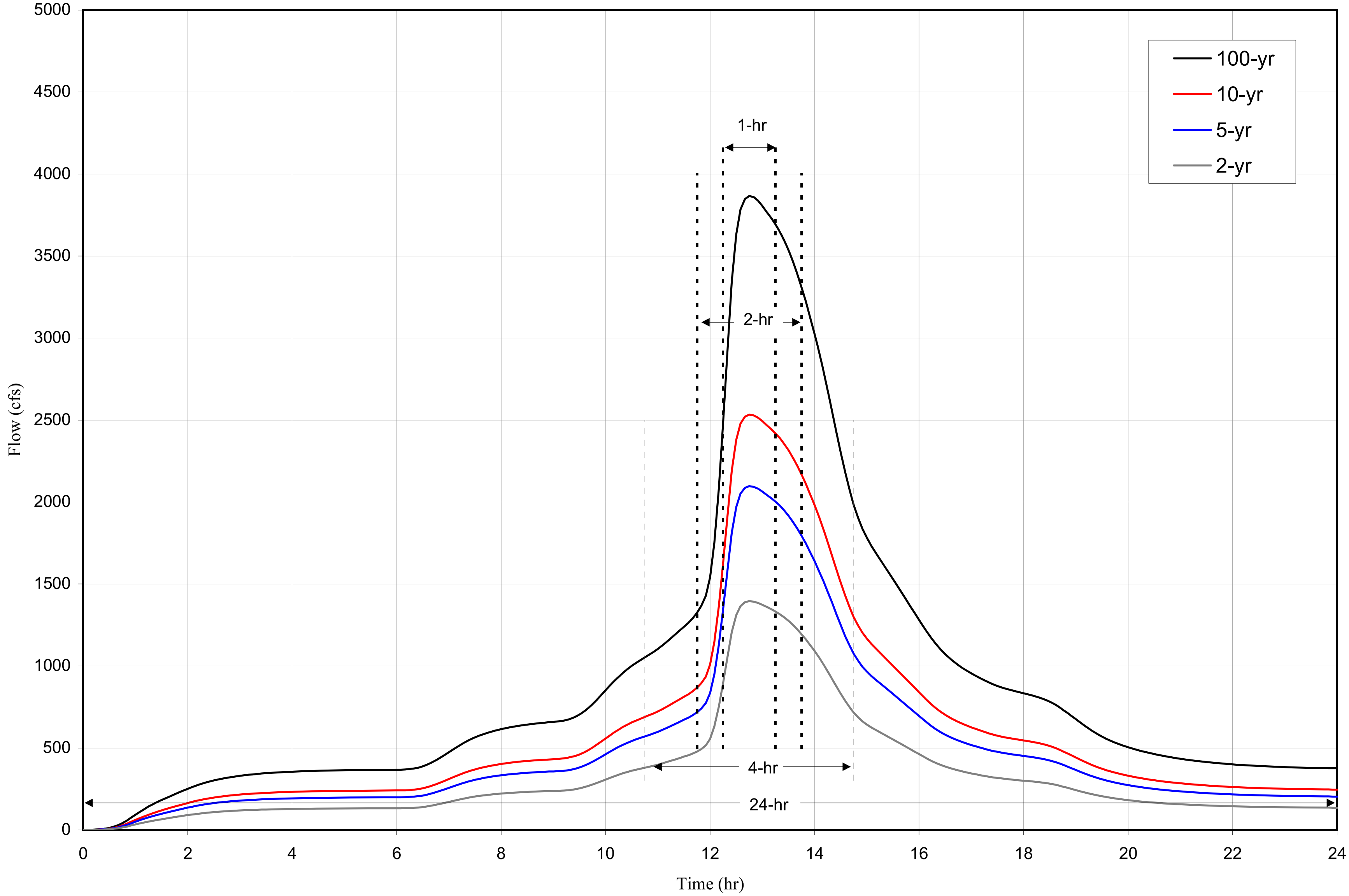


Figure 3.3 Flood Hydrographs at Prairie City Road for Proposed Conditions

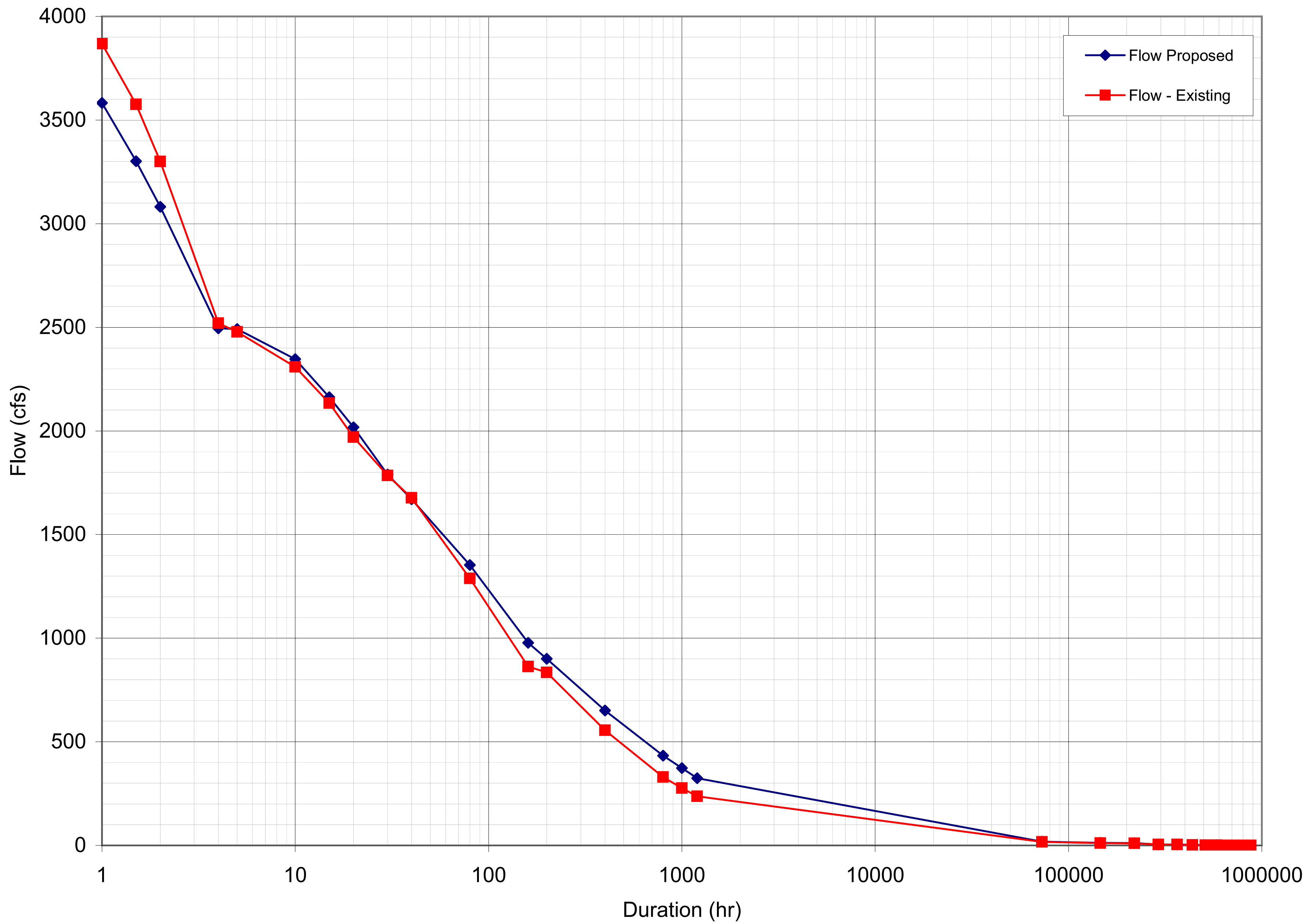


Figure 3.4   Flow duration curve at Prairie City Road over 100-year (876,000 hours) period.

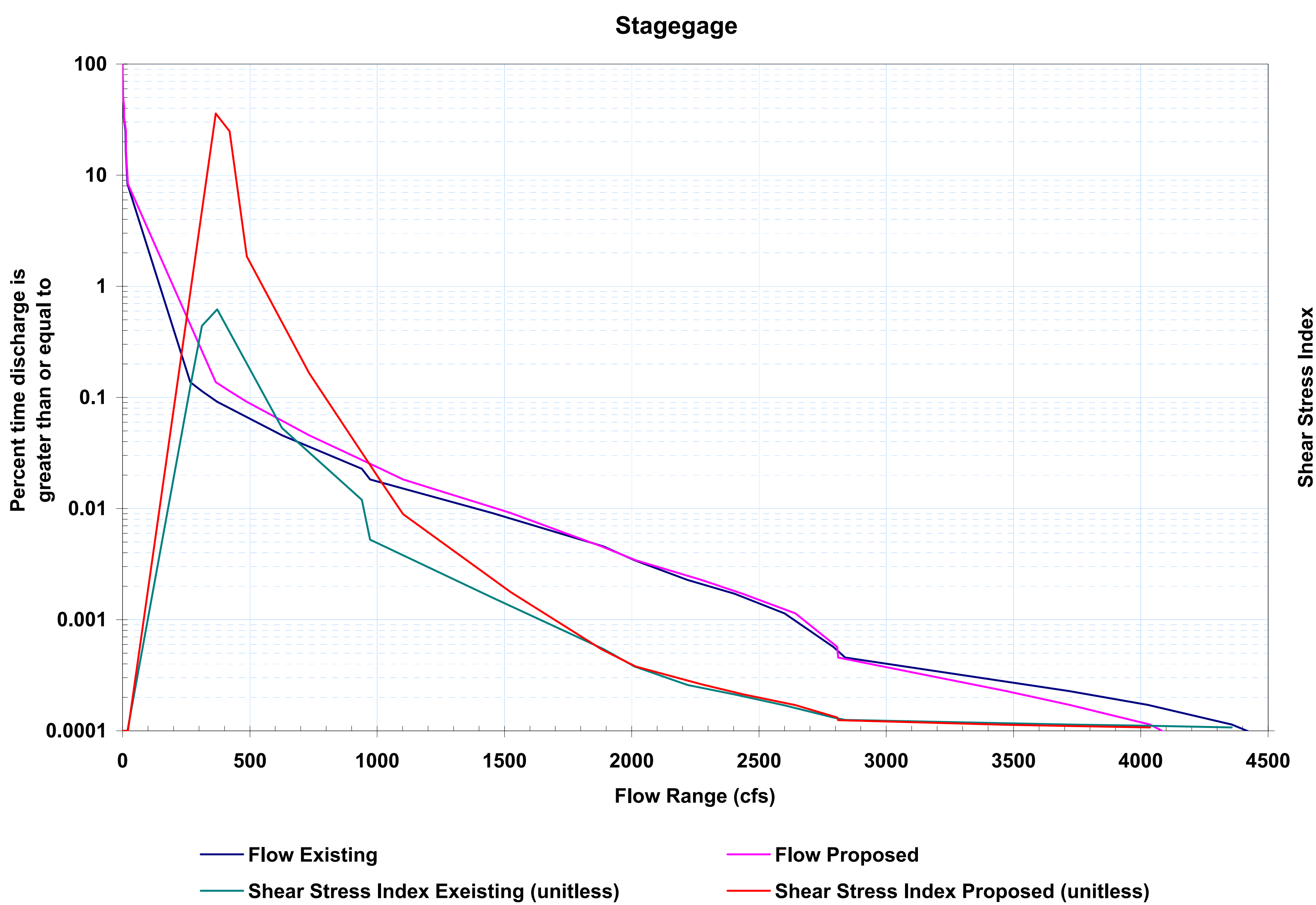


Figure 3.5 Shear stress index relationship at Stagegage index point.

Appendix 1

Cross-Section Surveys

Longitudinal Profiles

Bed Material Particle Size Distributions

Field Photos

Appendix 1
Cross-Section Surveys

<u>Notes:</u>

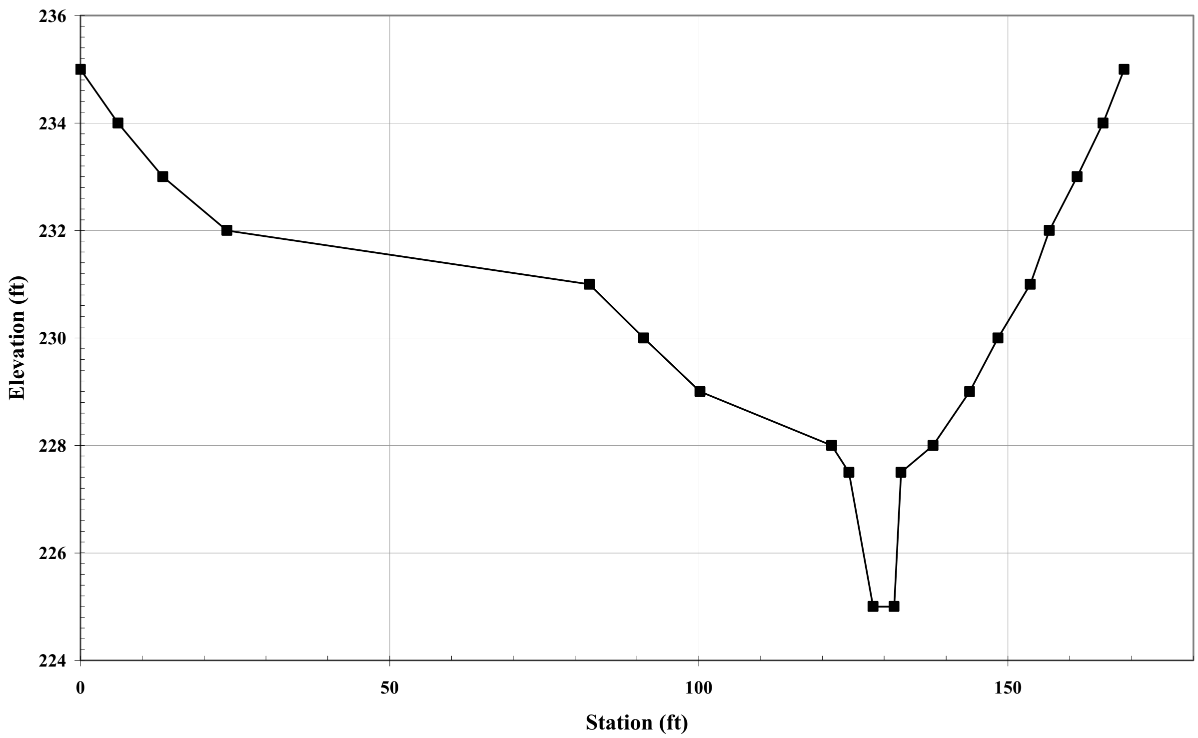
Cross-section surveys for Sites 5, 6, 7, 8, and 9 collected for this study by Mackay & Somps, Inc.

Cross-section for Site 3 obtained from 1-ft contour topography provided by Mackay & Somps (2005).

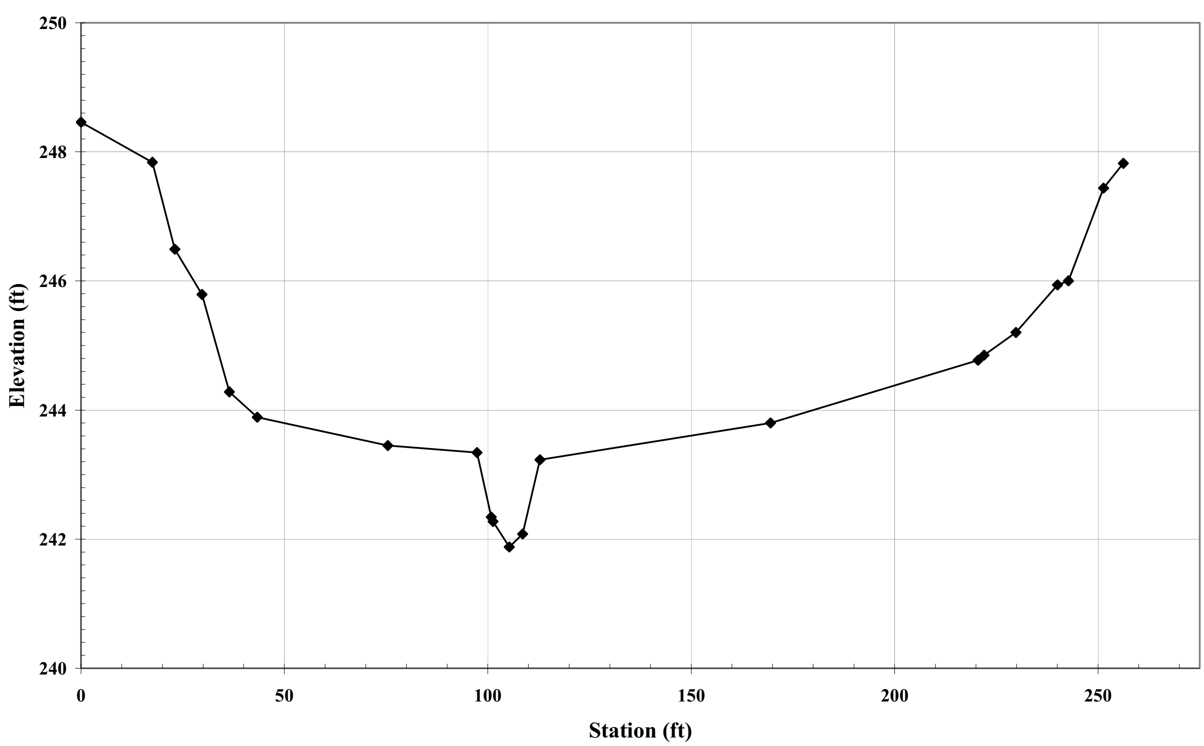
Cross-sections for Sites 11, 12, 13, and 14 obtained from 2-ft contour topography provided by Mackay Somps (2006).

Cross-section surveys for Sites ECORP-1, 2, 3, 4 and Stagegage collected by ECORP Inc. (Christner, pers. comm.)

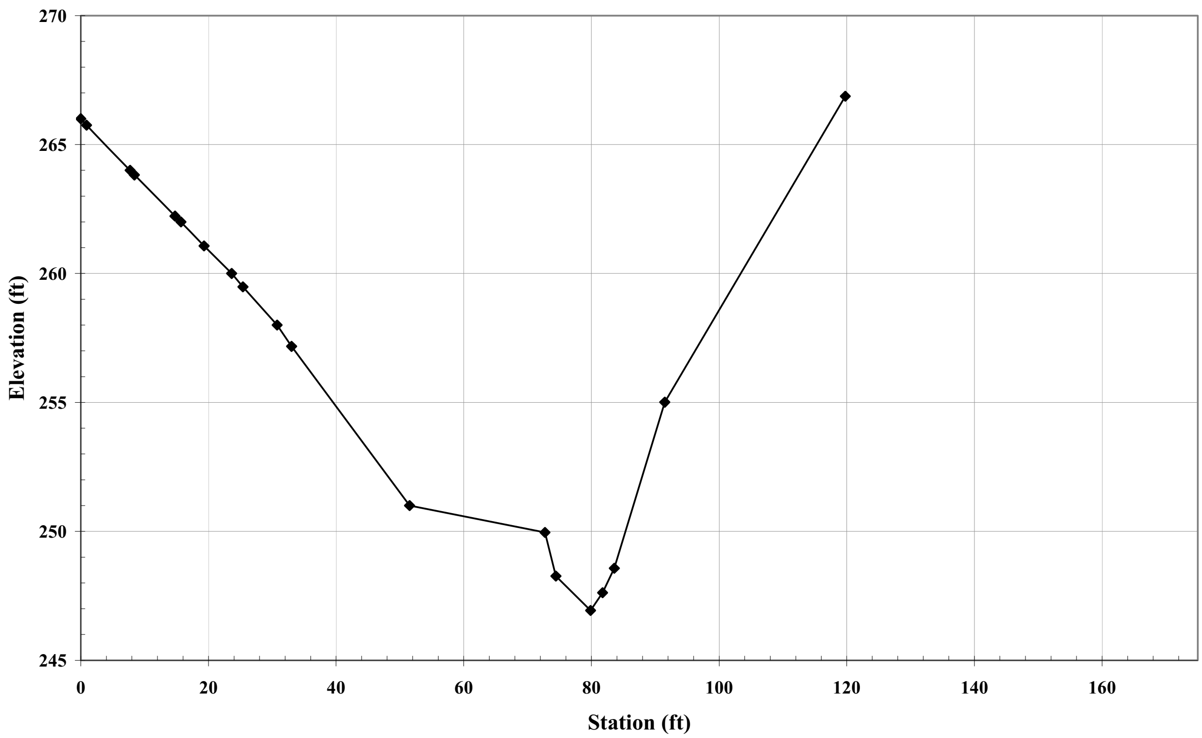
Cross-section at Site 3



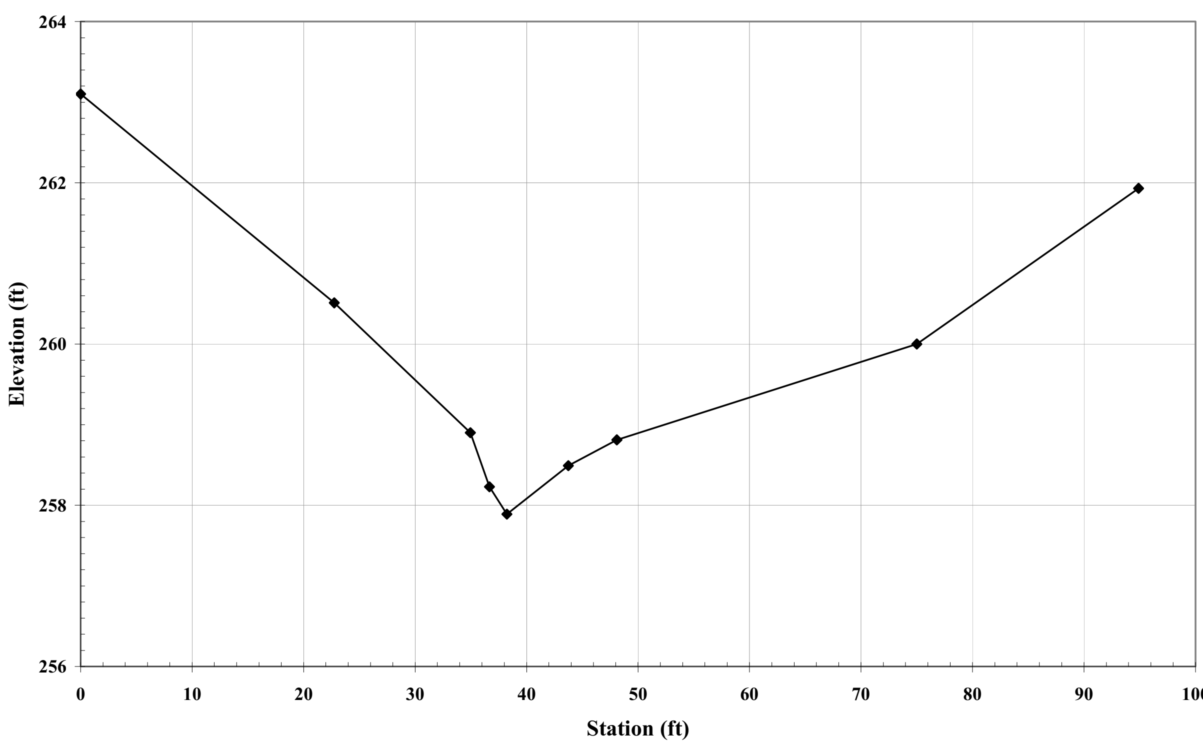
Cross-section at Site 5



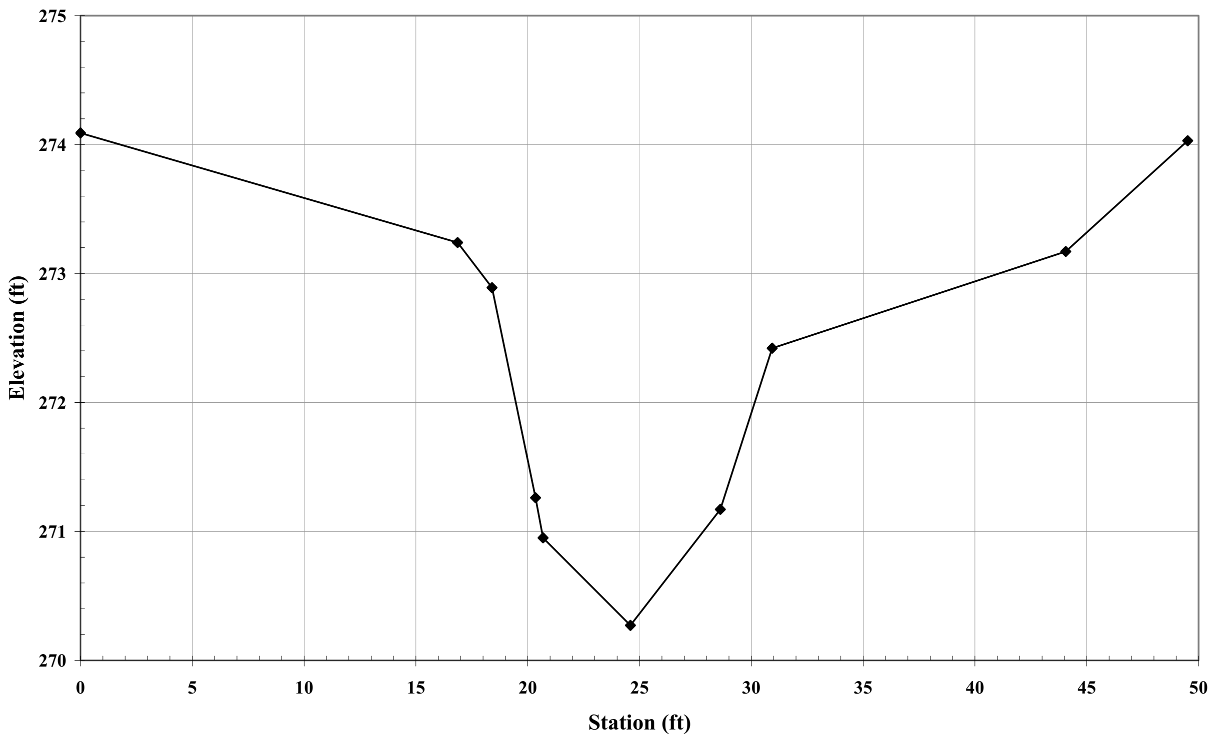
Cross-section at Site 6



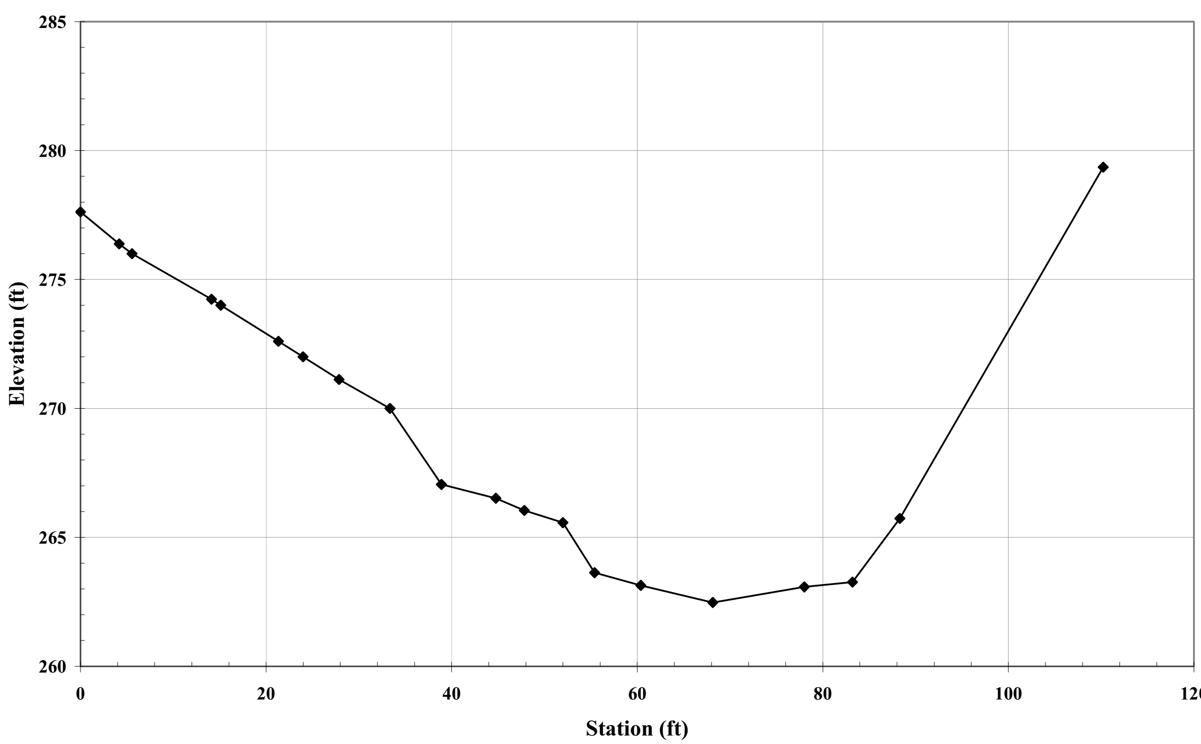
Cross-section at Site 7



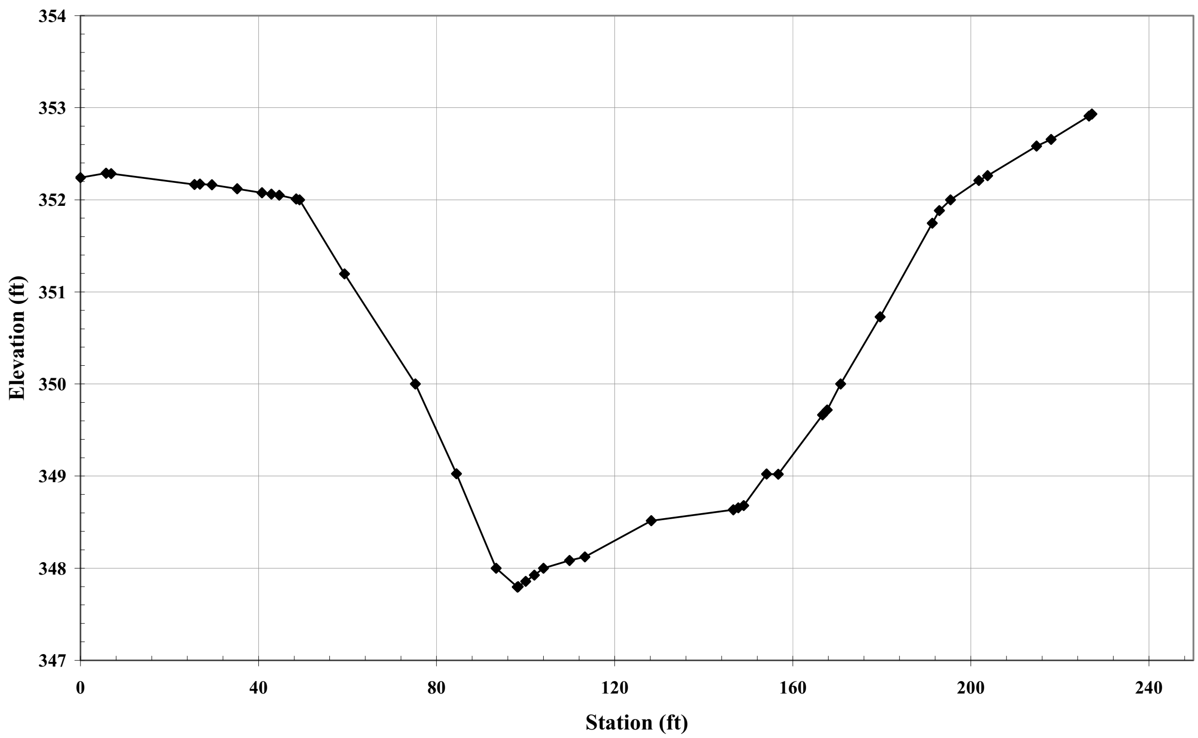
Cross-section at Site 8



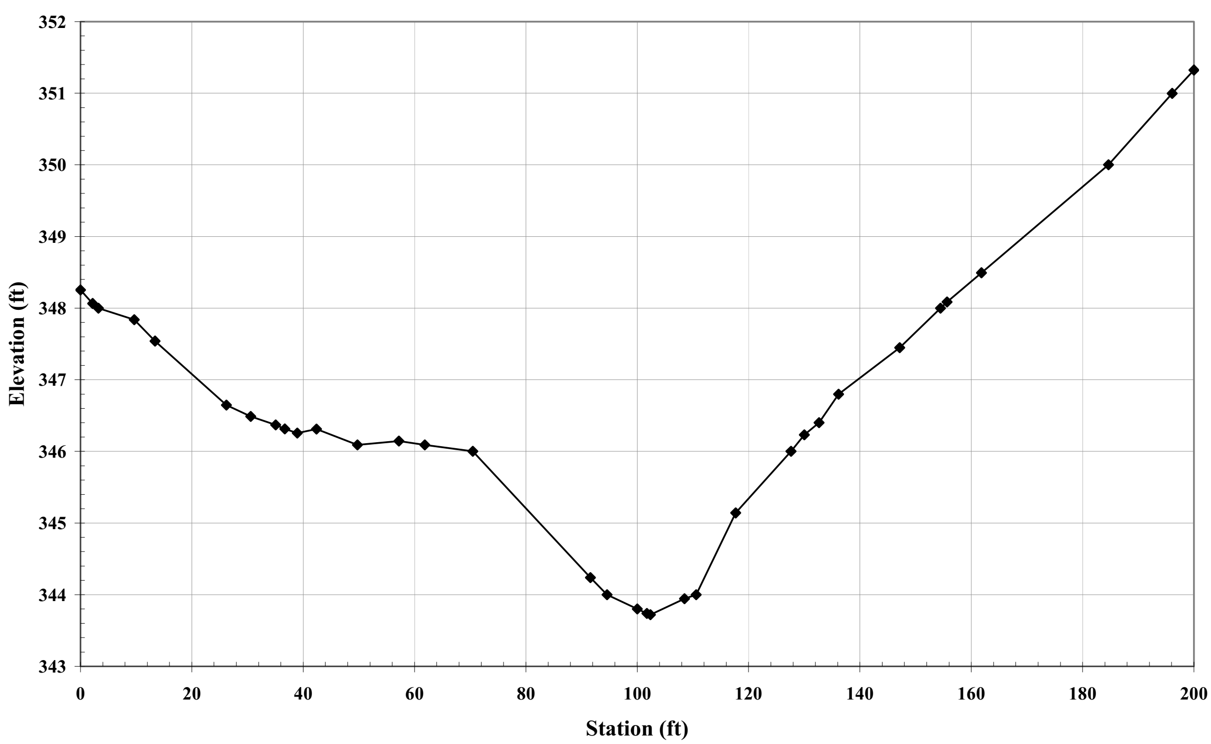
Cross-section at Site 9



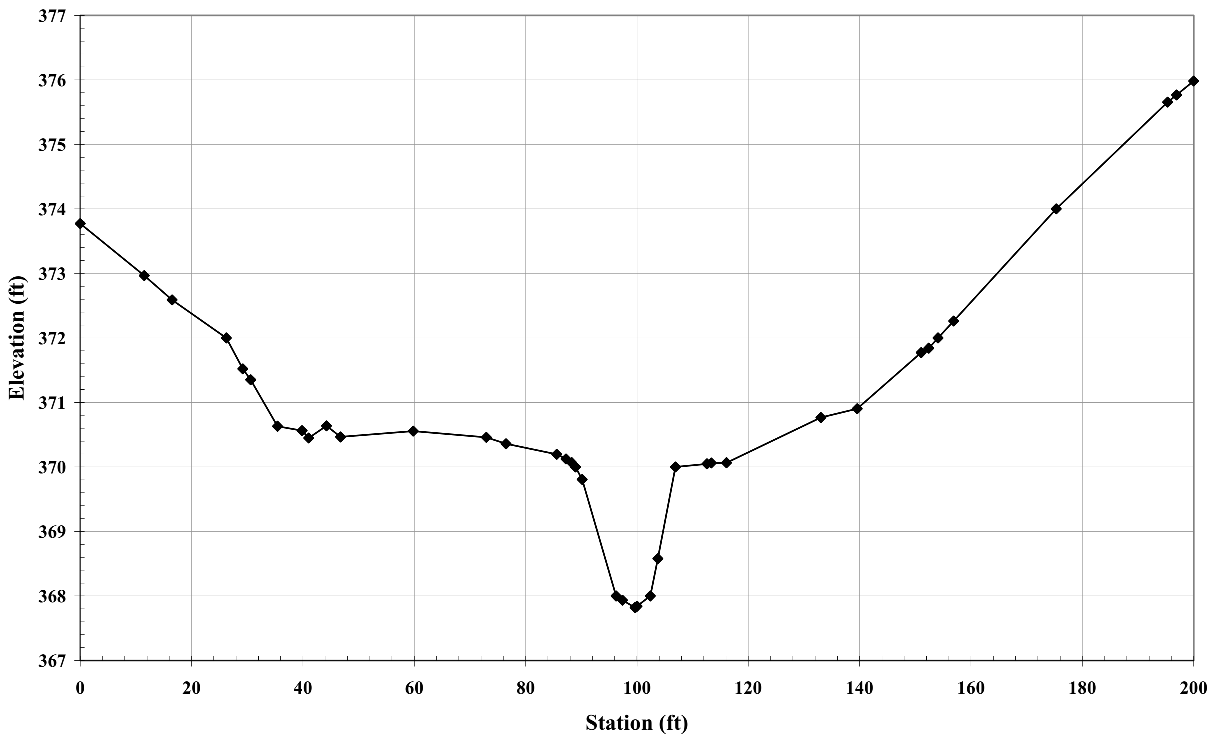
Cross-section at Site 11



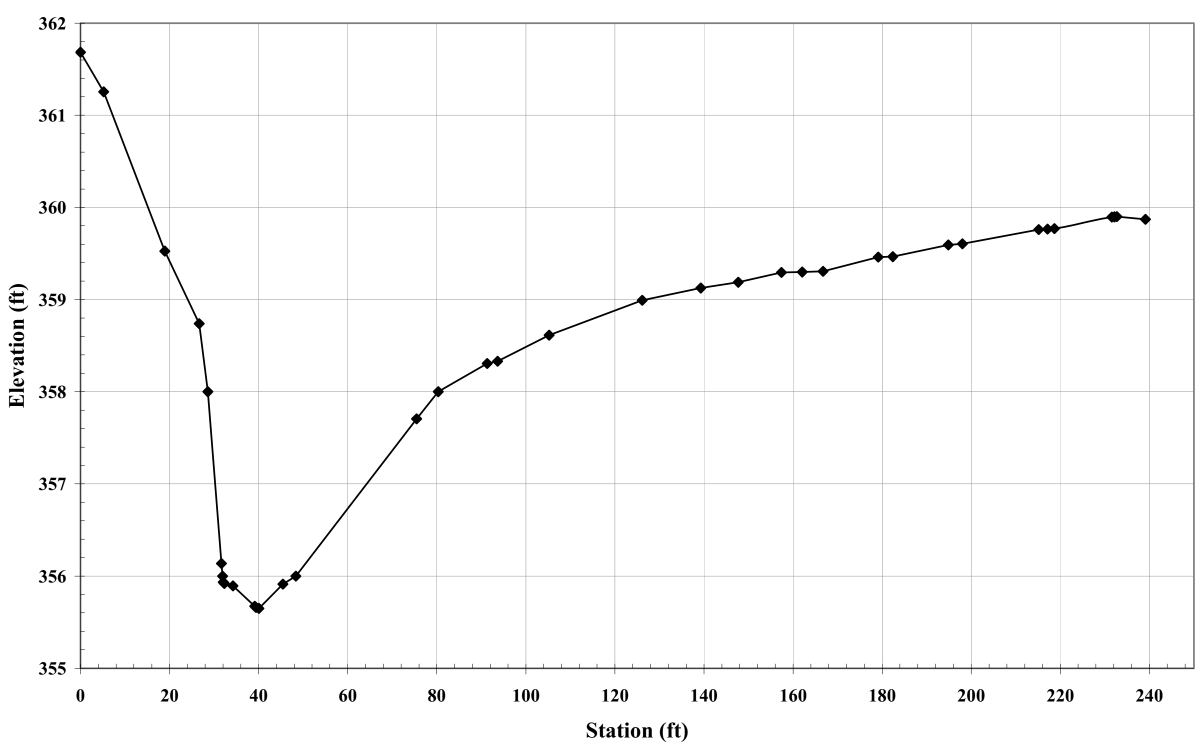
Cross-section at Site 12



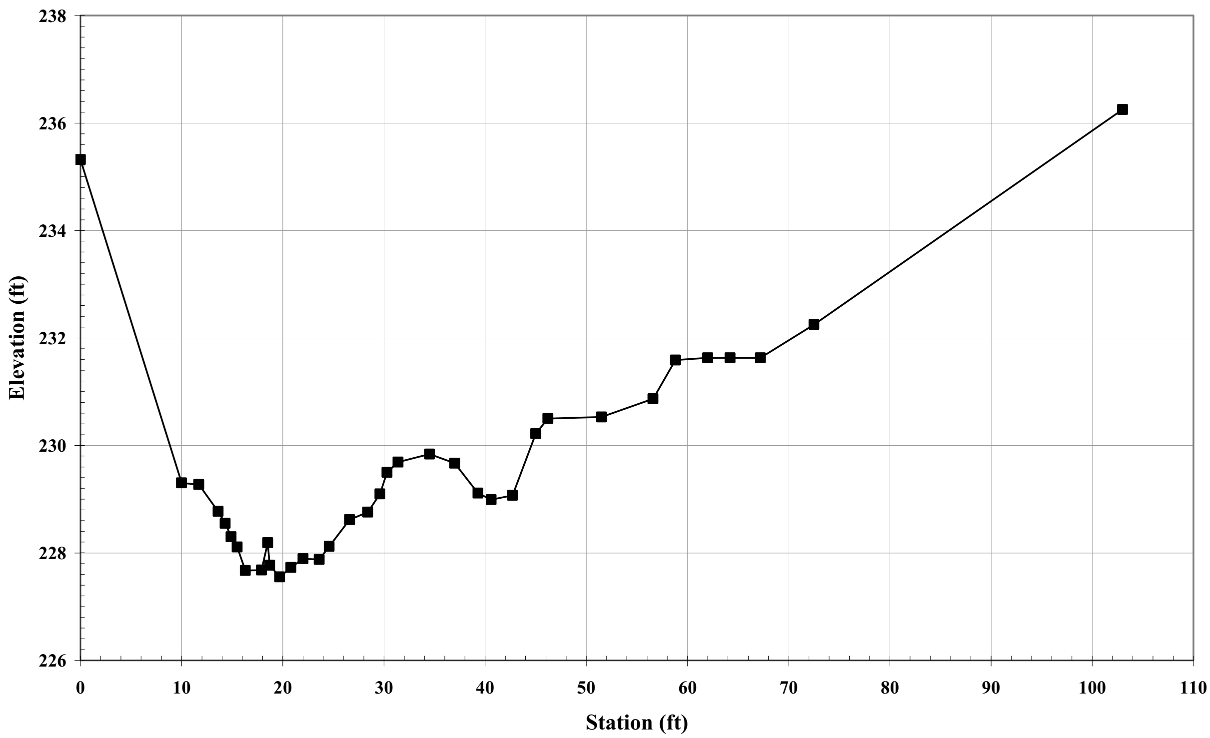
Cross-section at Site 13



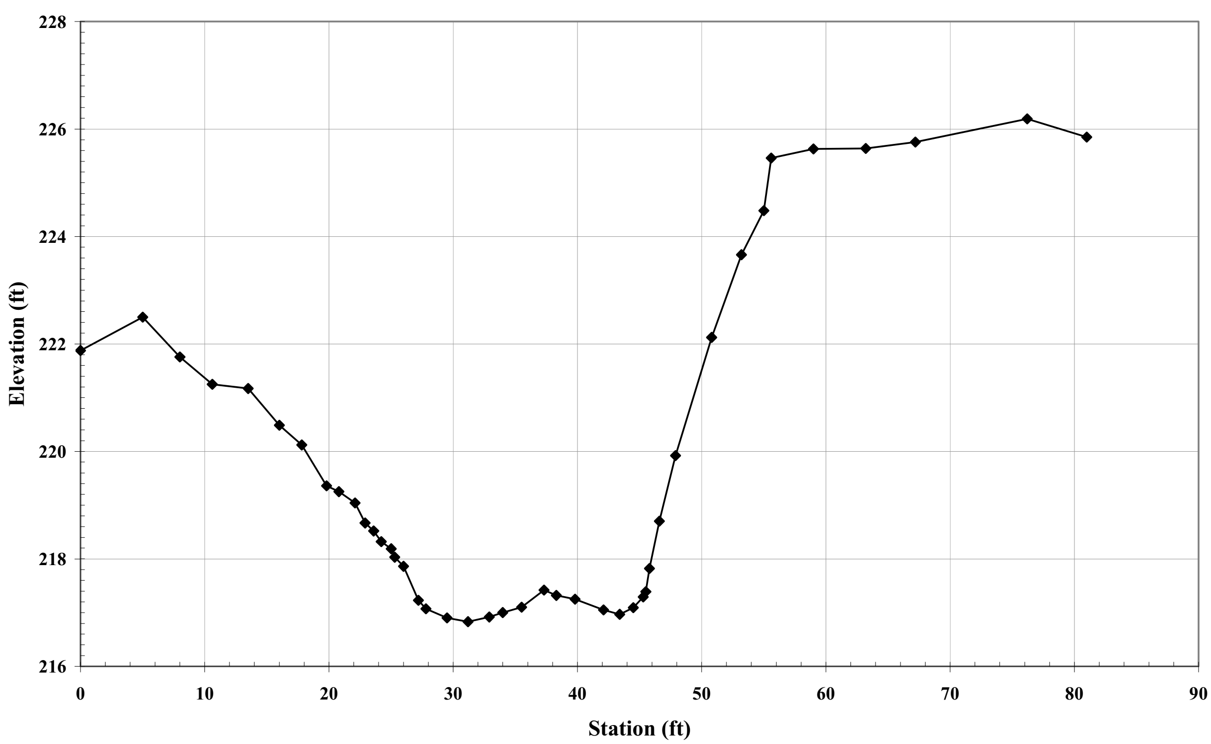
Cross-section at Site 14



Cross-section at Site ECORP-1



Cross-section at Site ECORP-2



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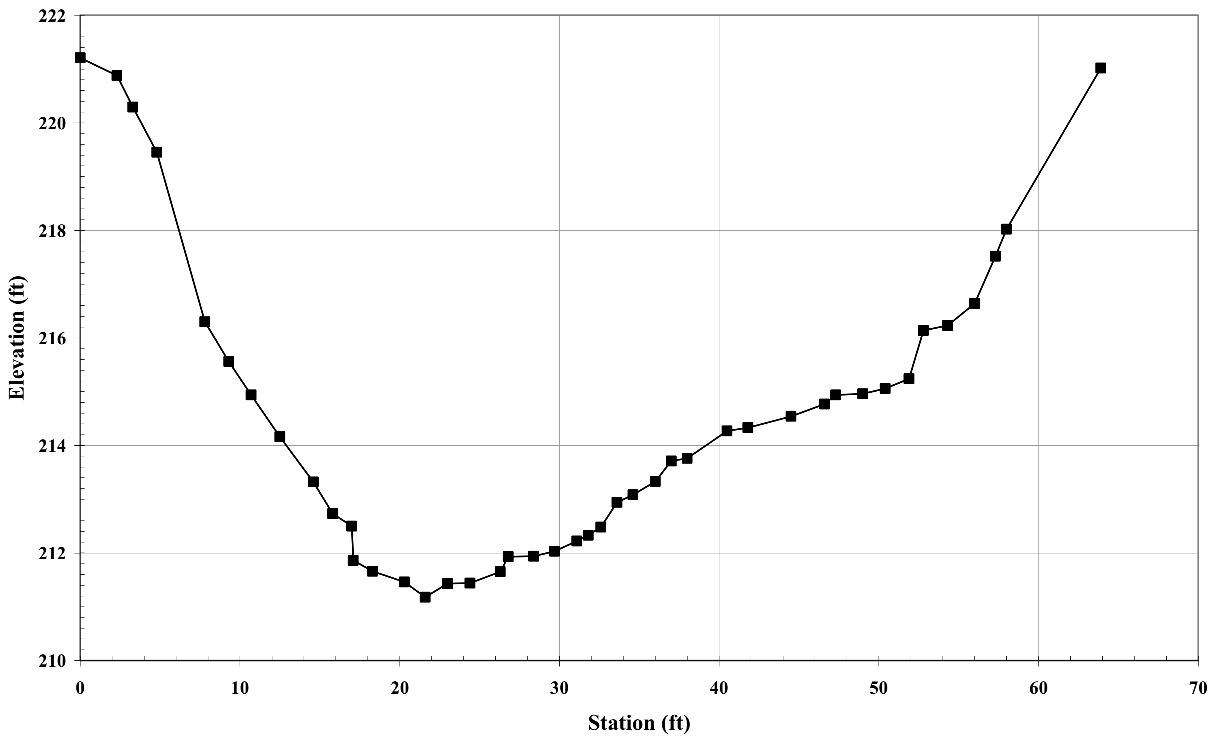
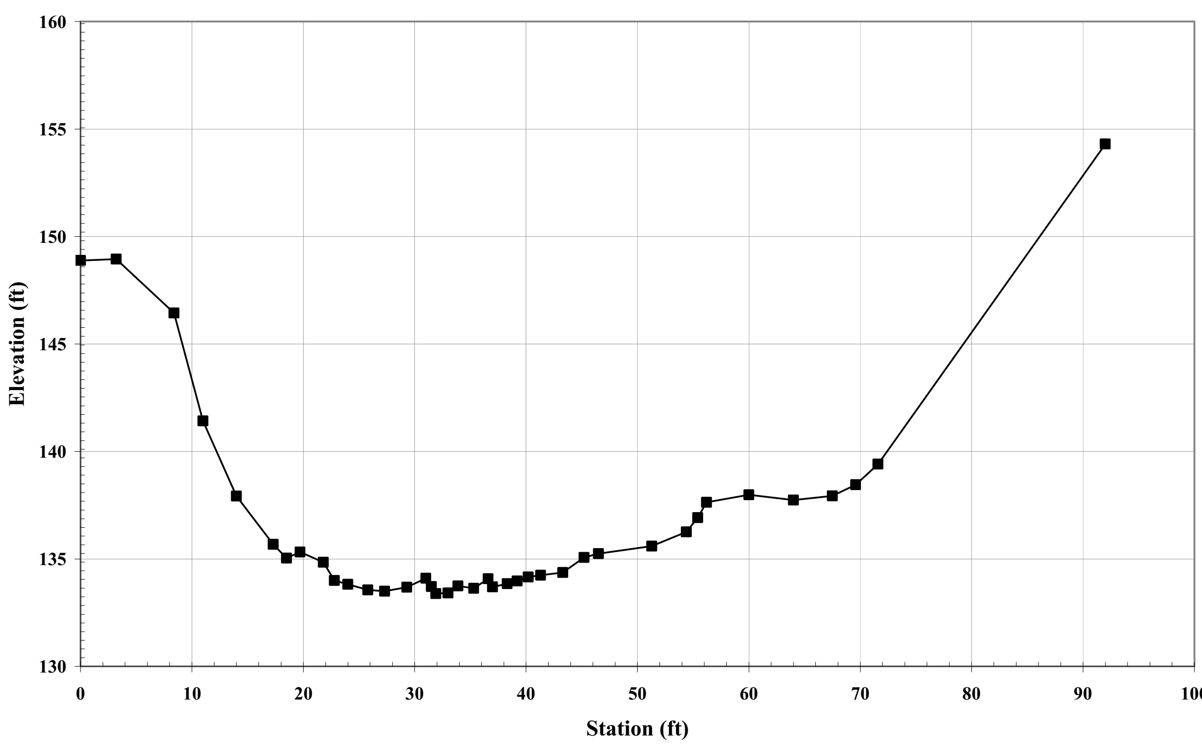
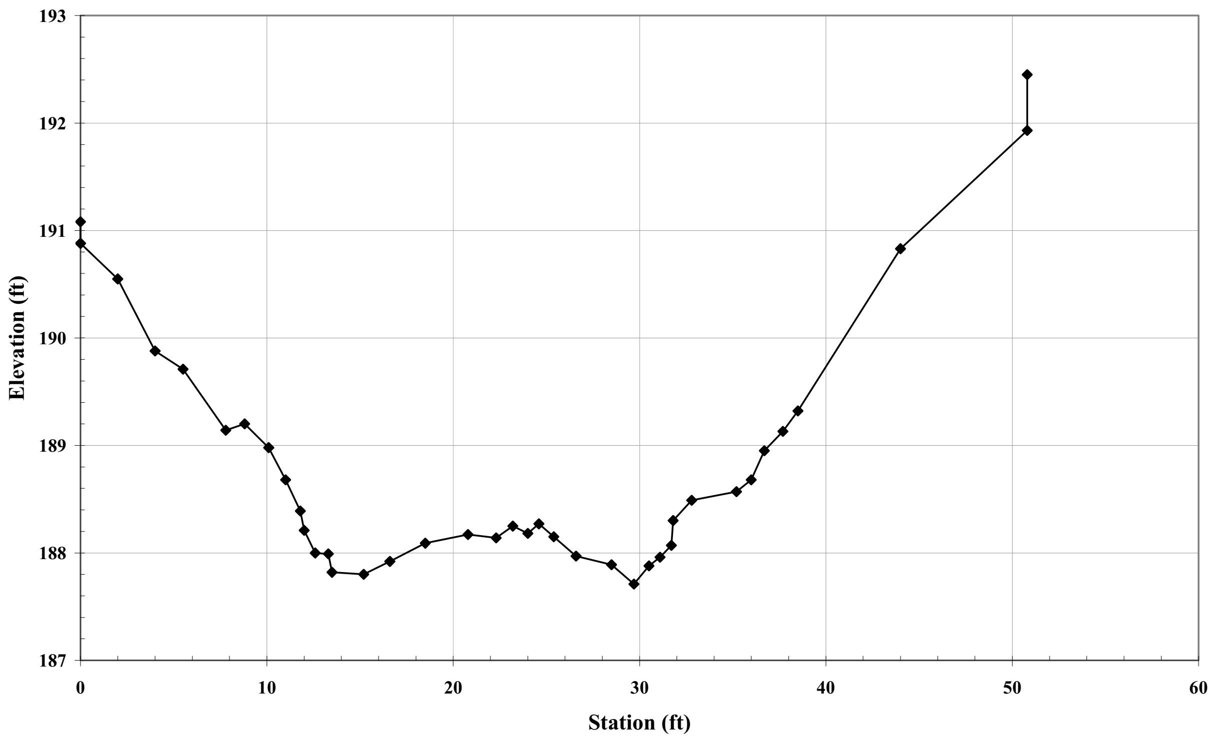


Cross-section at Site ECORP-4



Cross-section at Site Stagegage



Appendix 1
Longitudinal Profiles

<u>Notes:</u>

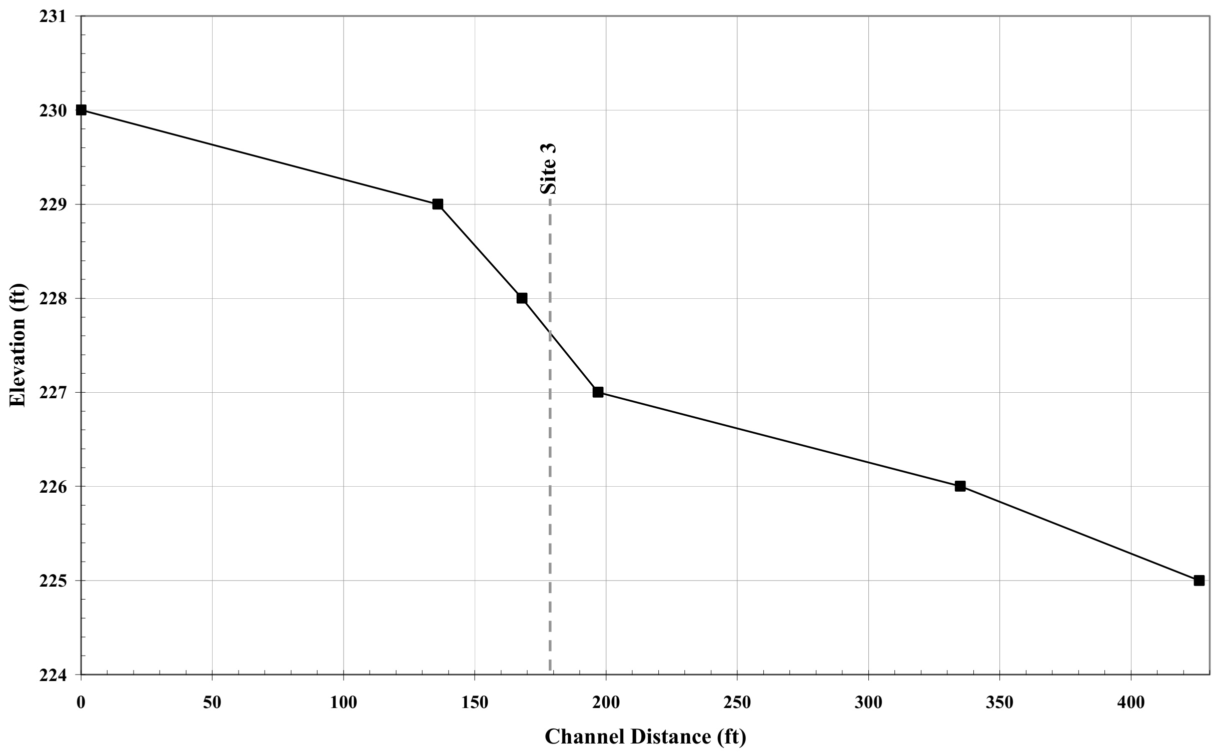
Longitudinal profiles for Sites 5, 6, 7, 8, and 9 collected for this study by Mackay & Somps, Inc.

Longitudinal profile for Site 3 obtained from 1-ft contour topography provided by Mackay & Somps (2005).

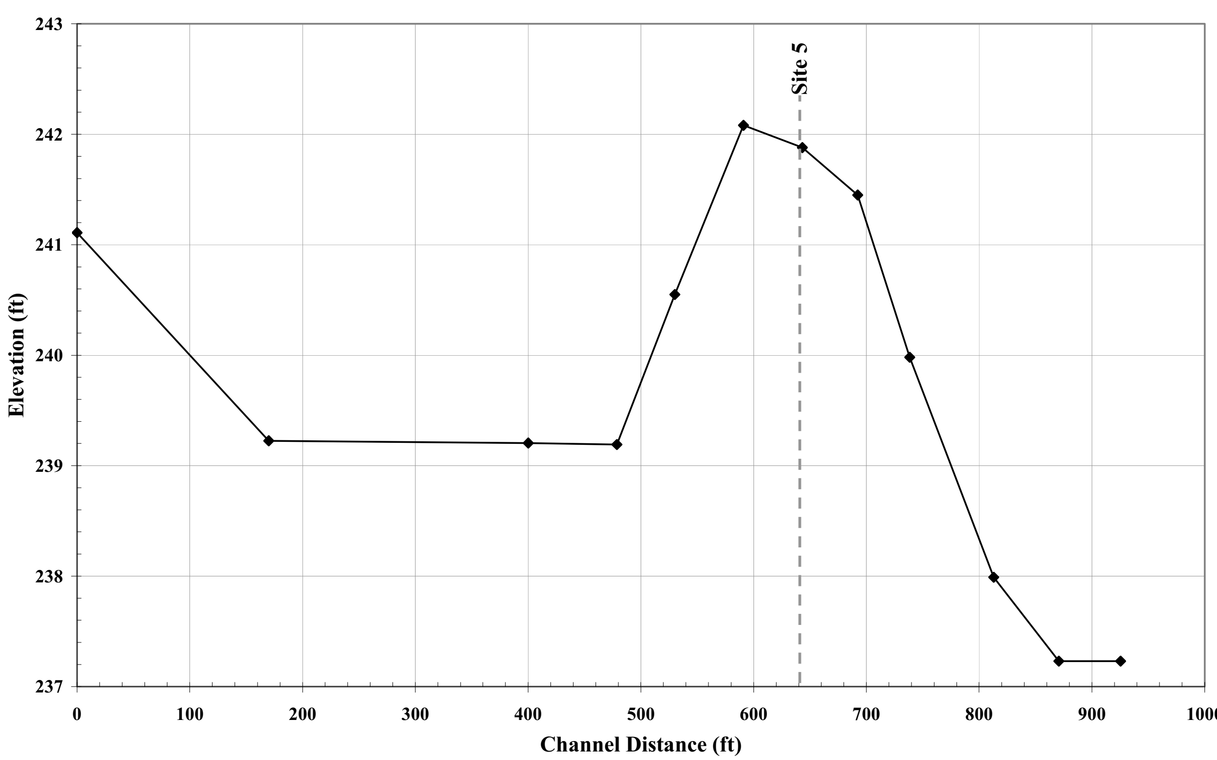
Longitudinal profiles for Sites 11, 12, 13, and 14 obtained from 2-ft contour topography provided by Mackay Somps (2006).

Longitudinal profiles for Sites ECORP-1, 2, 3, 4 and Stagegage collected by ECORP Inc. (Christner, pers. comm.)

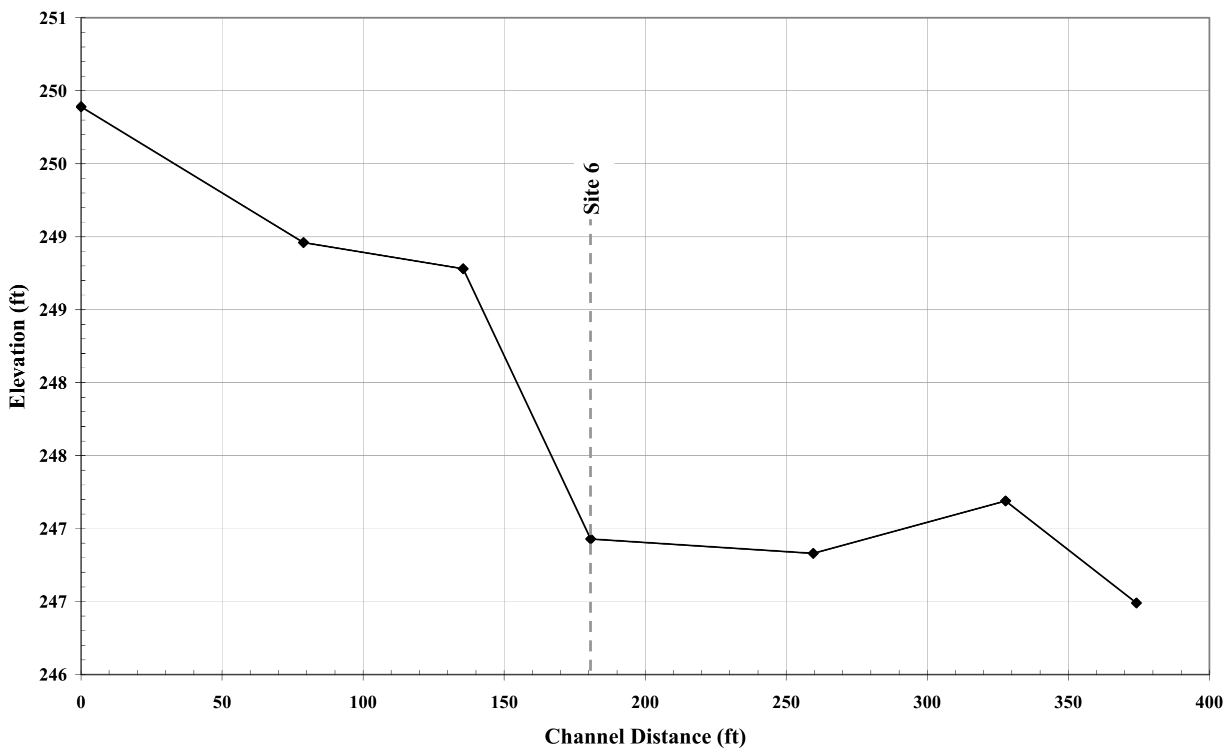
Longitudinal Profile at Site 3



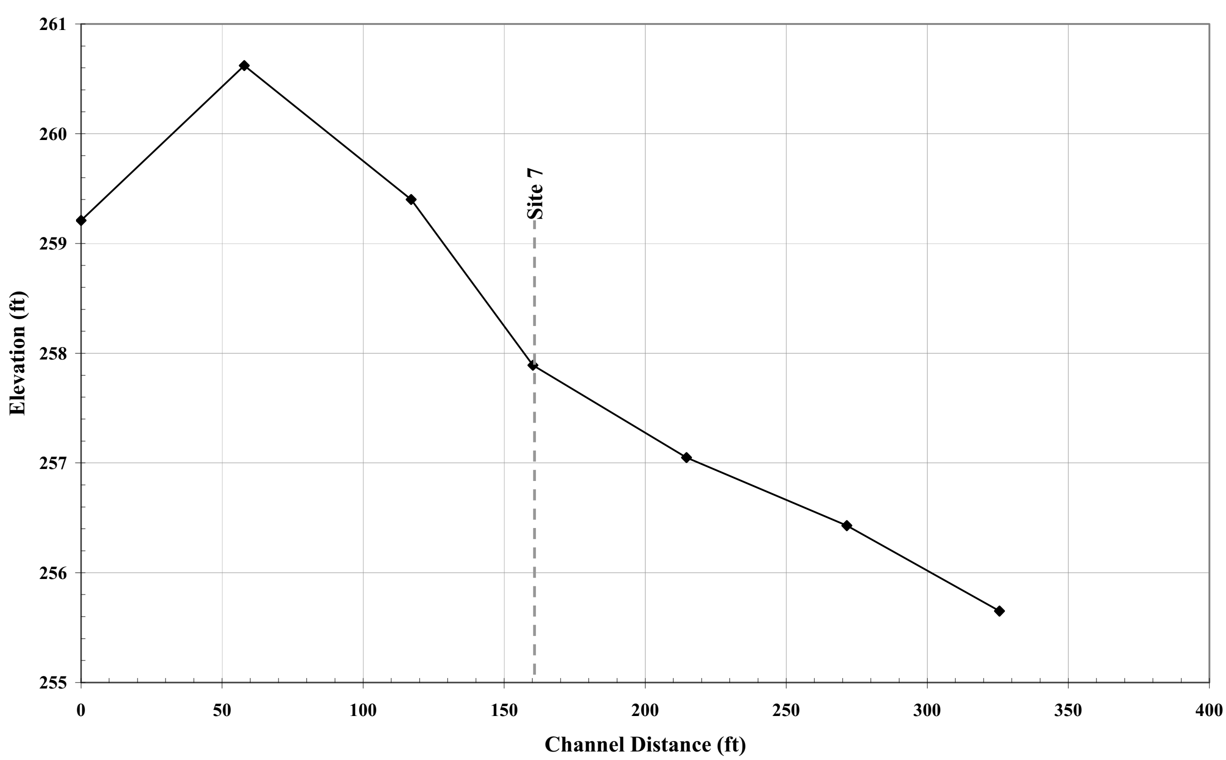
Longitudinal Profile at Site 5



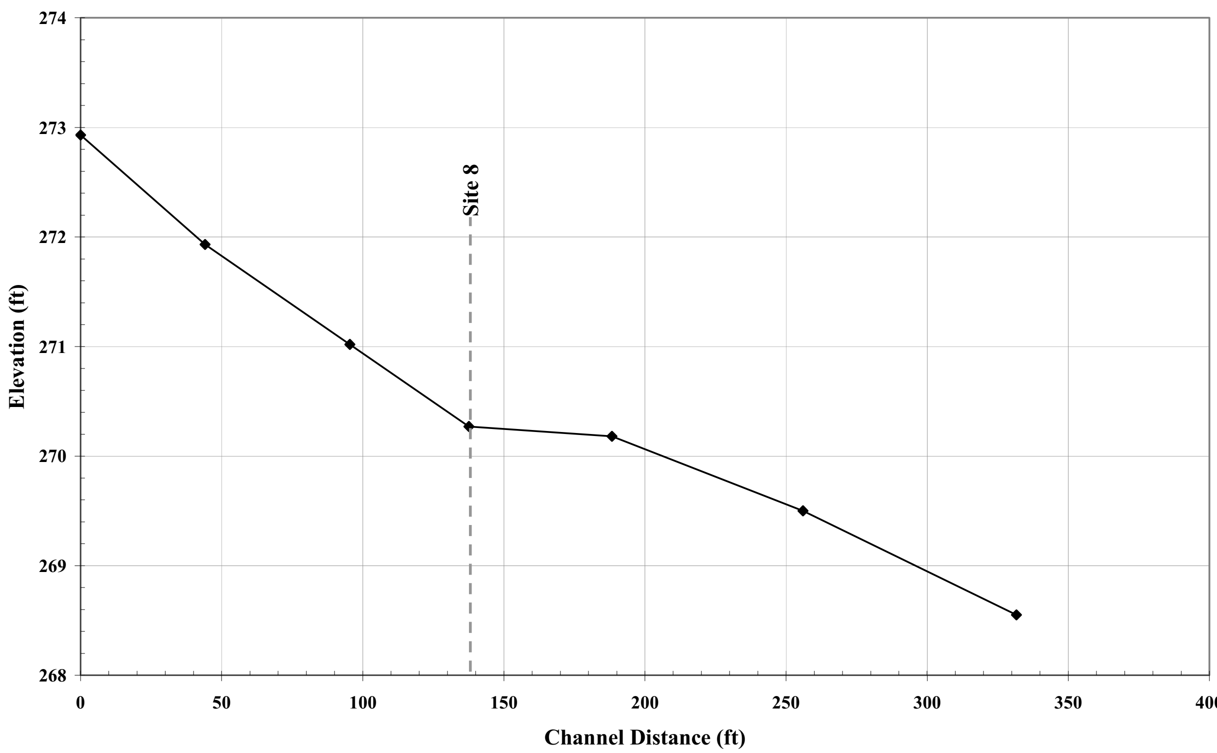
Longitudinal Profile at Site 6



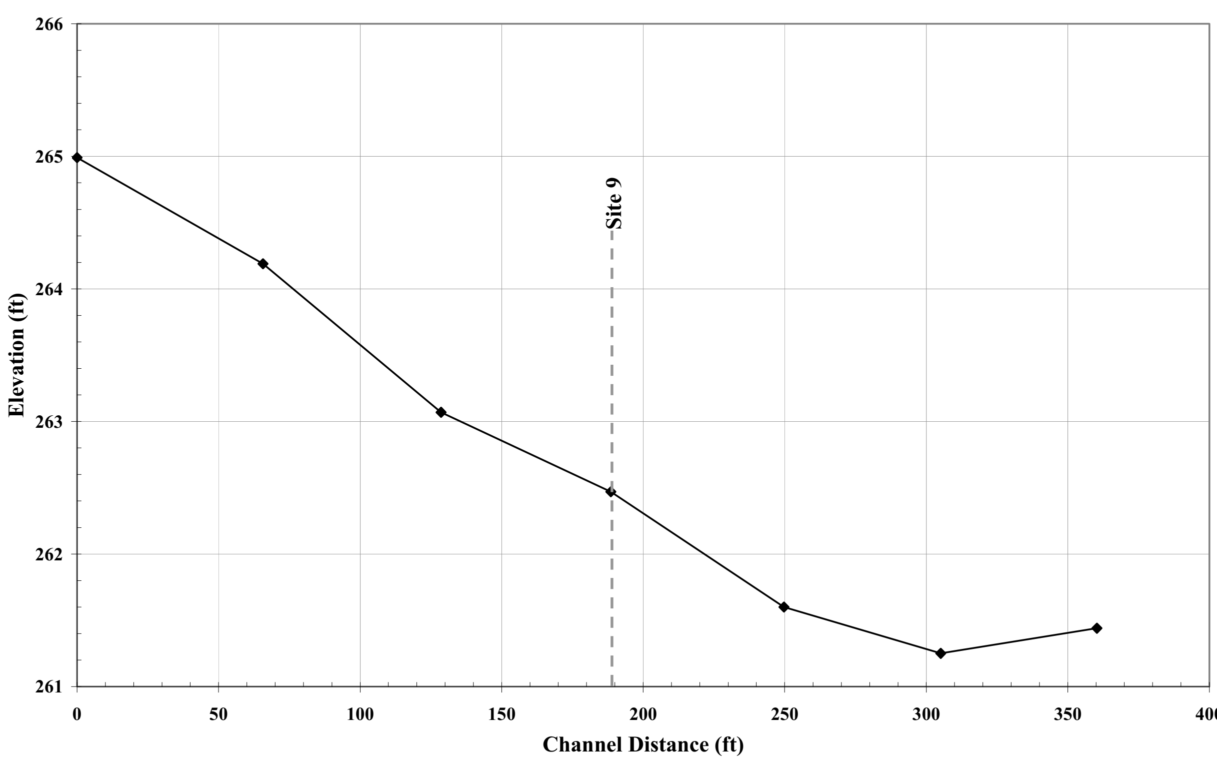
Longitudinal Profile at Site 7



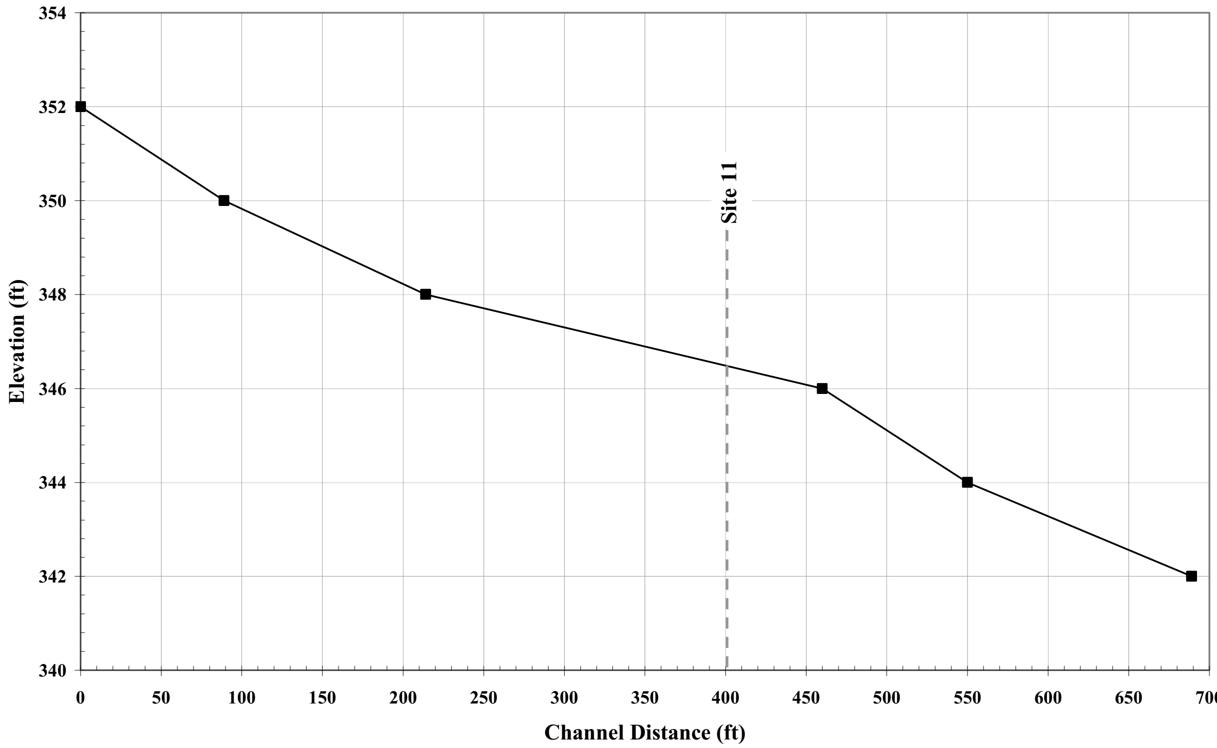
Longitudinal Profile at Site 8



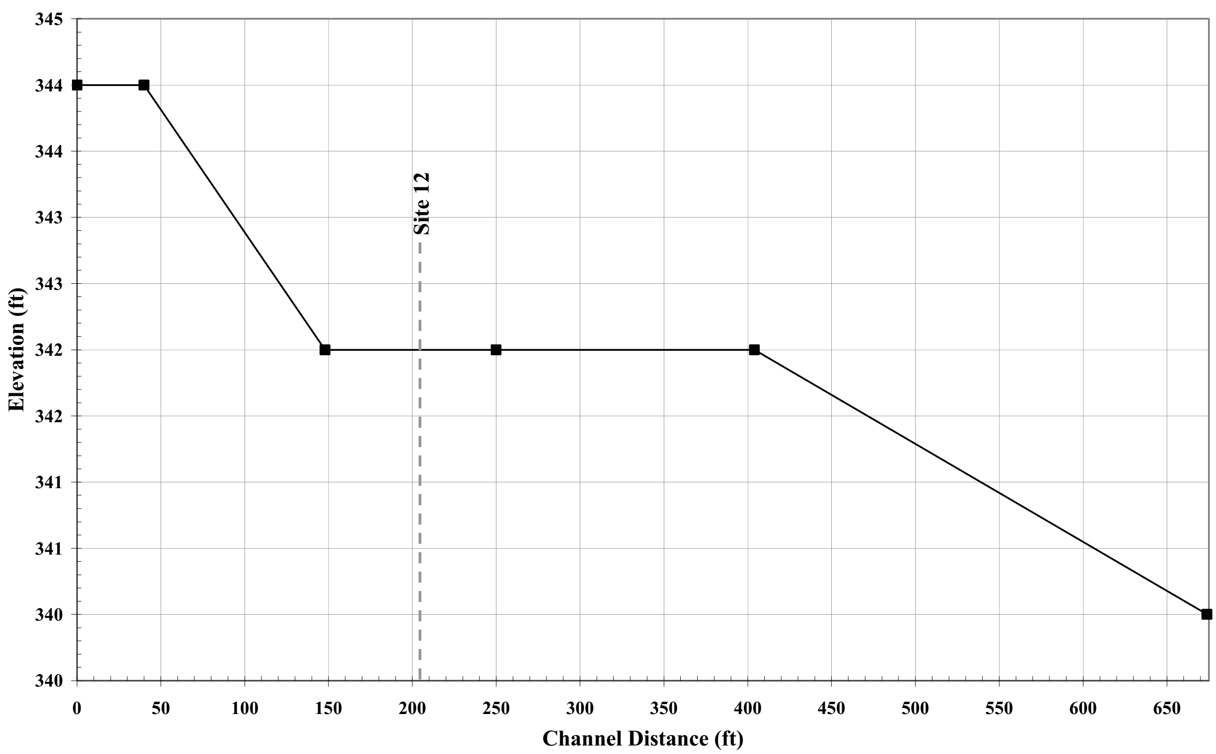
Longitudinal Profile at Site 9



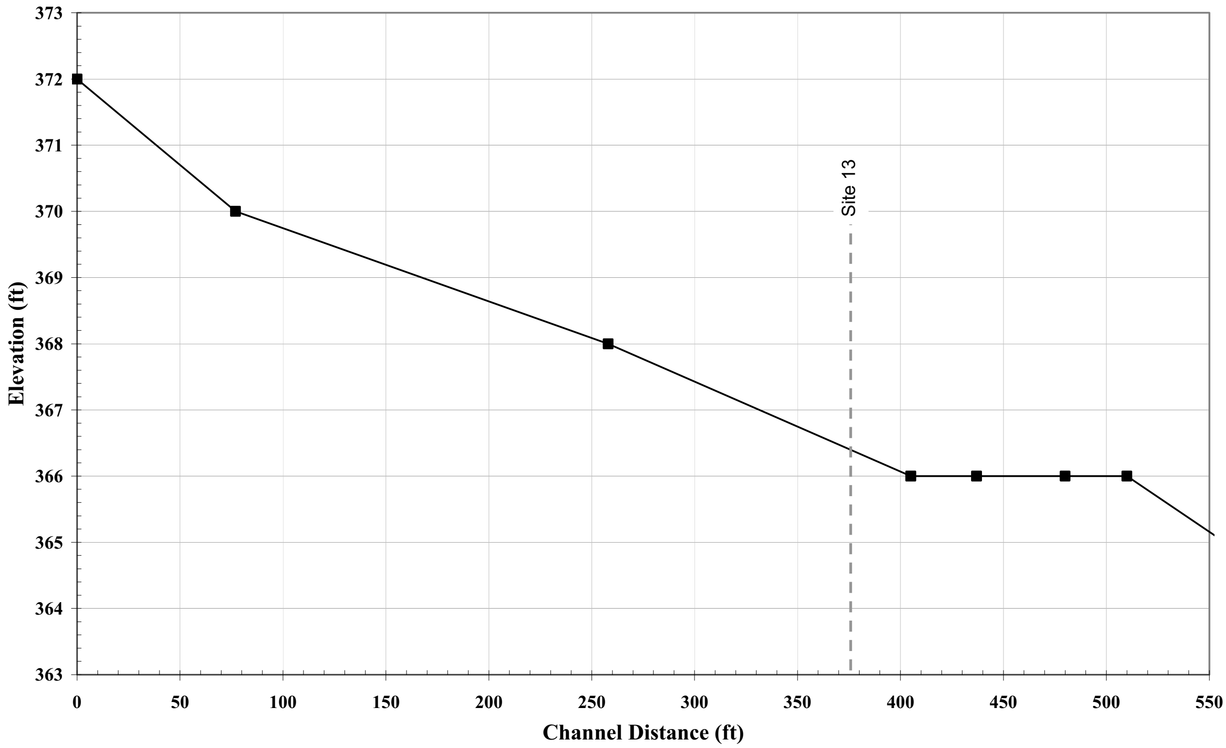
Longitudinal Profile at Site 11



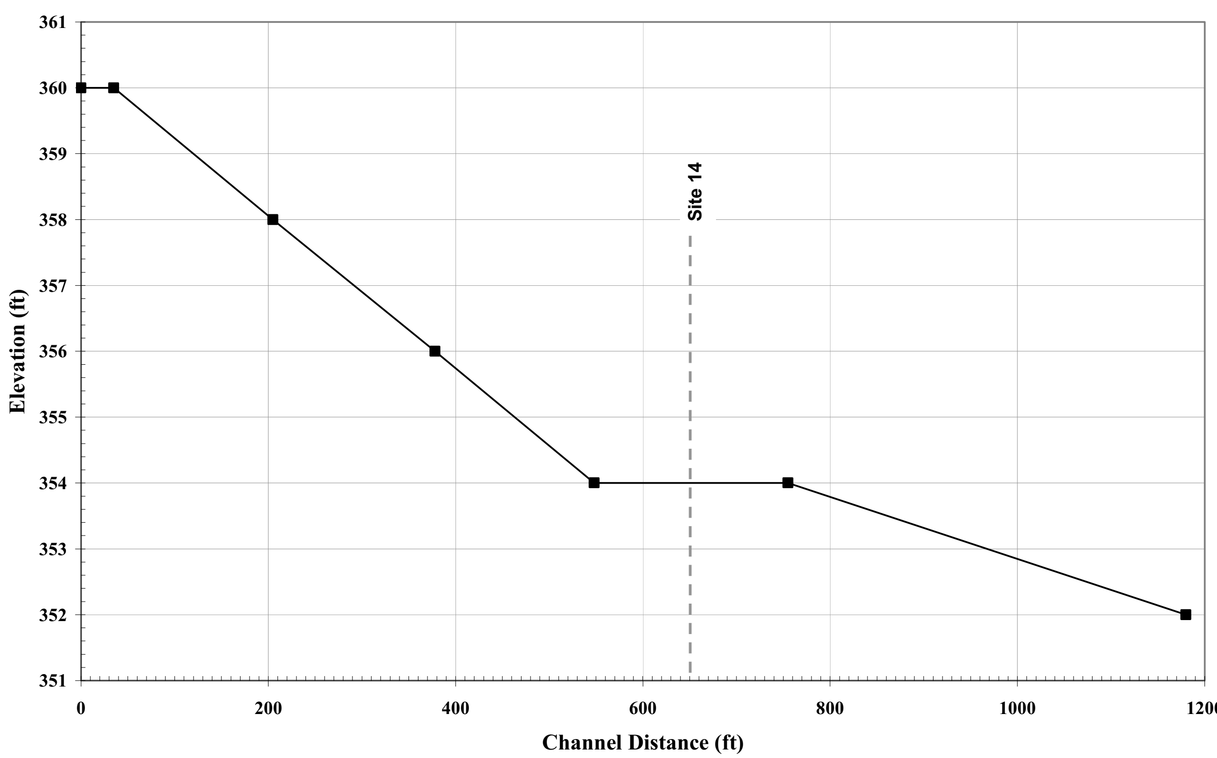
Longitudinal Profile at Site 12



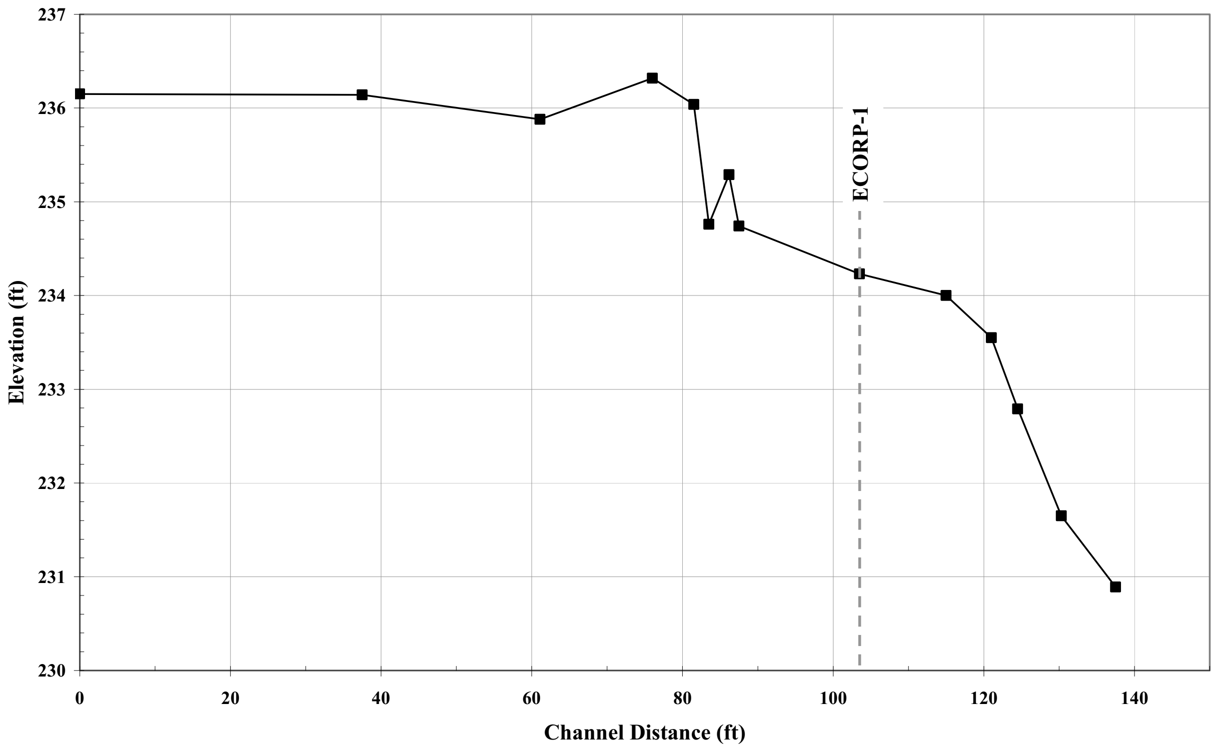
Longitudinal Profile at Site 13



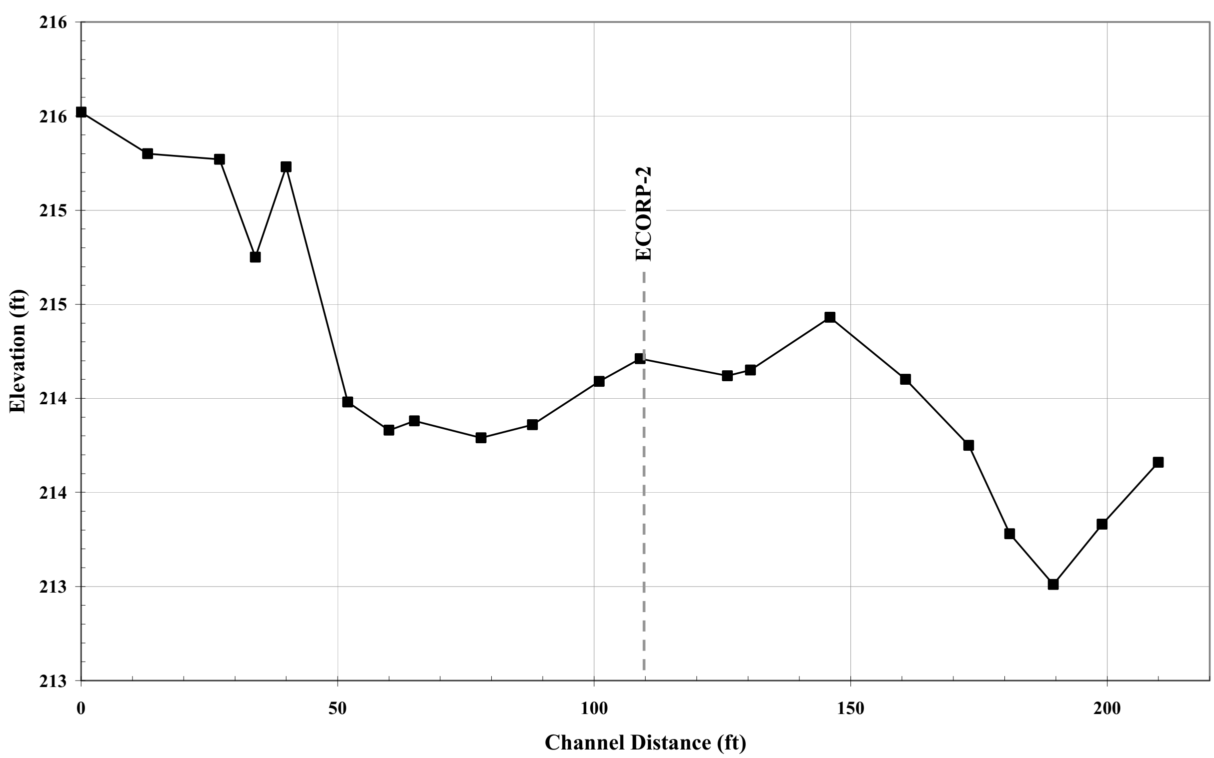
Index Point #14 Longitudinal Profile



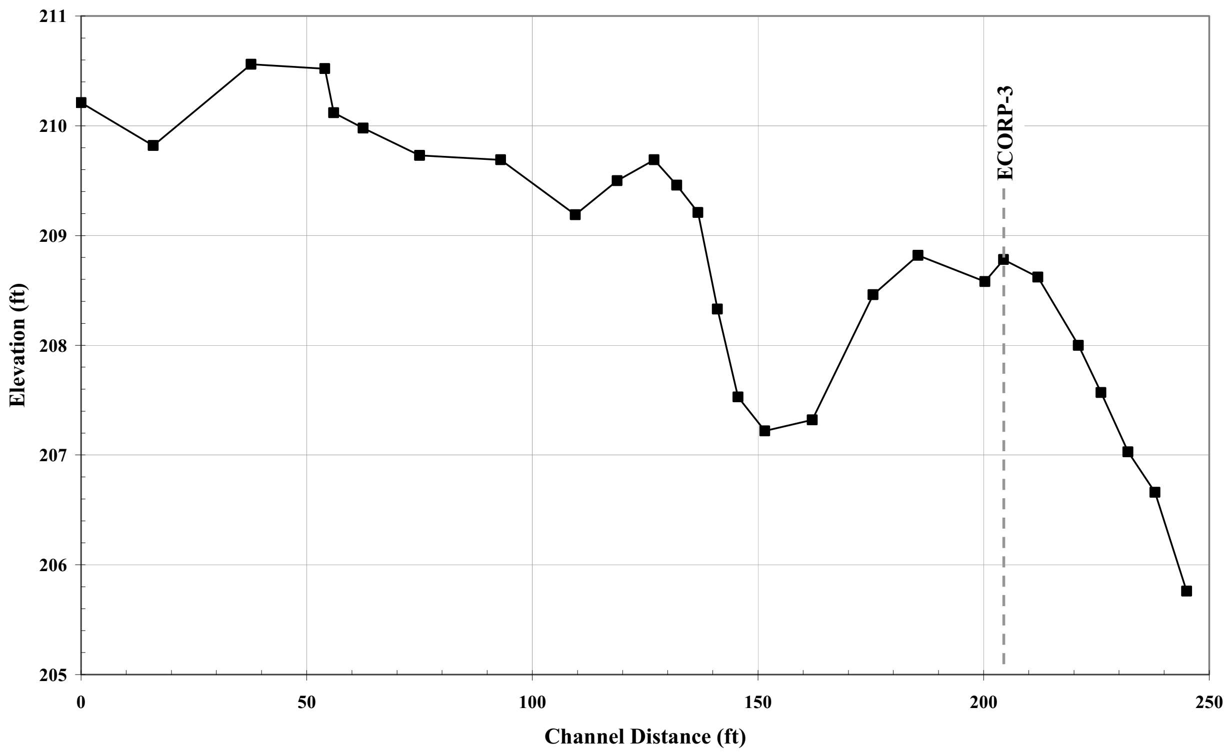
Longitudinal Profile at Site ECORP-1



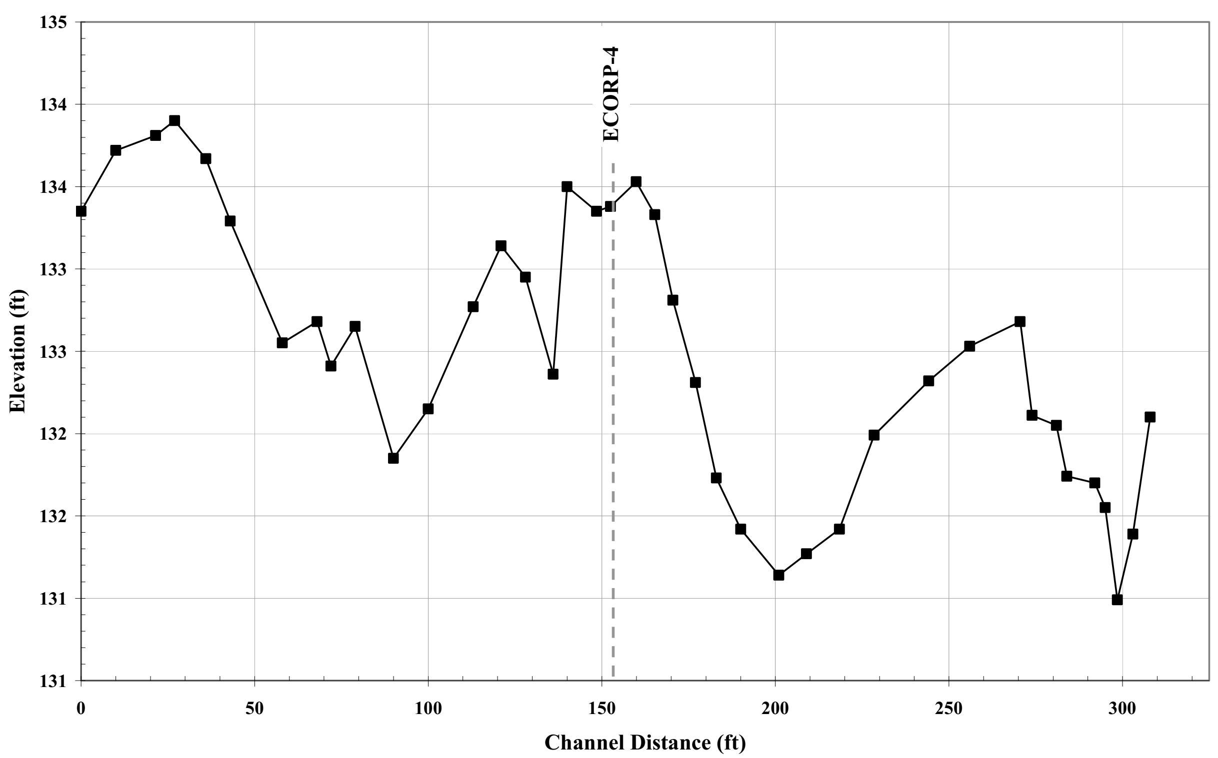
Longitudinal Profile at Site ECORP-2



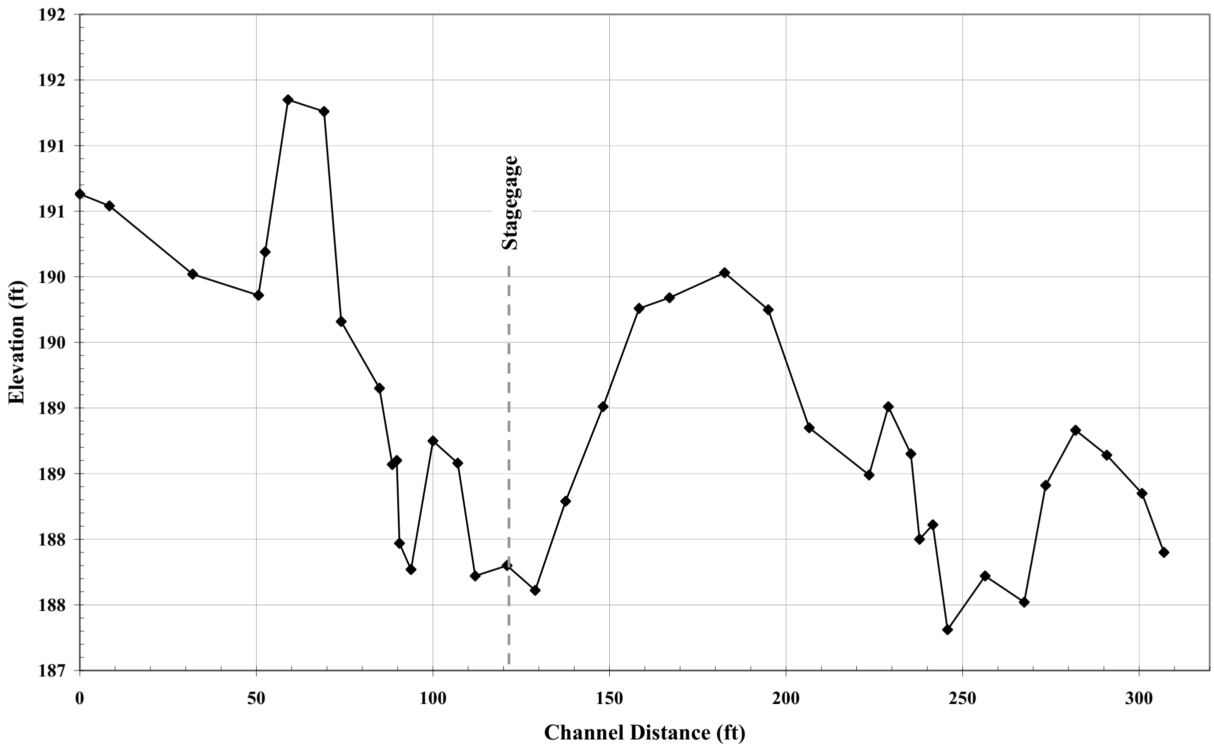
Longitudinal Profile at Site ECORP-3



Longitudinal Profile at Site ECORP-4



Longitudinal Profile at Site Stagegage



Appendix 1
Bed Material Particle Size Distributions

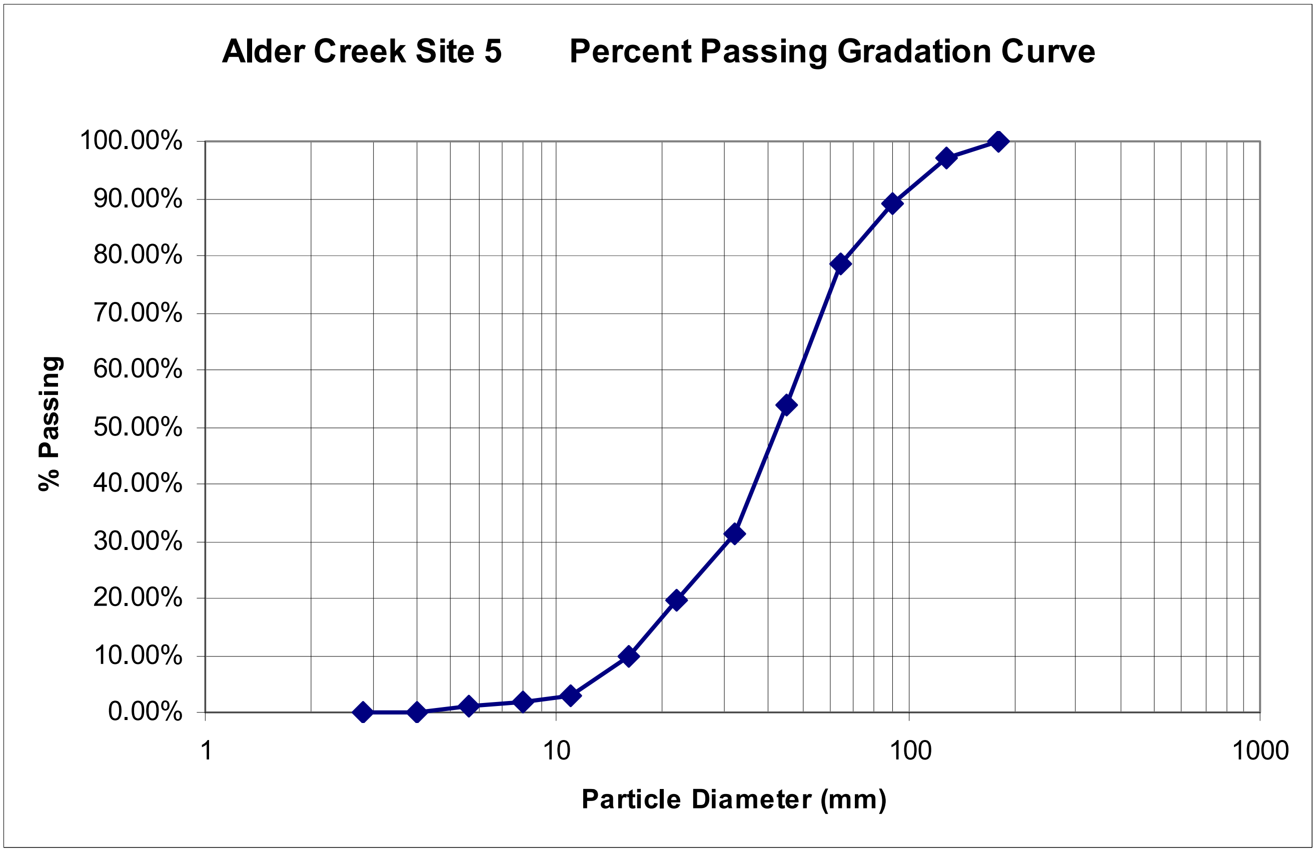
<u>Notes:</u>

Bed material samples for Sites 5, 6, 7, 8, and 9 collected for this study by **nhc**.

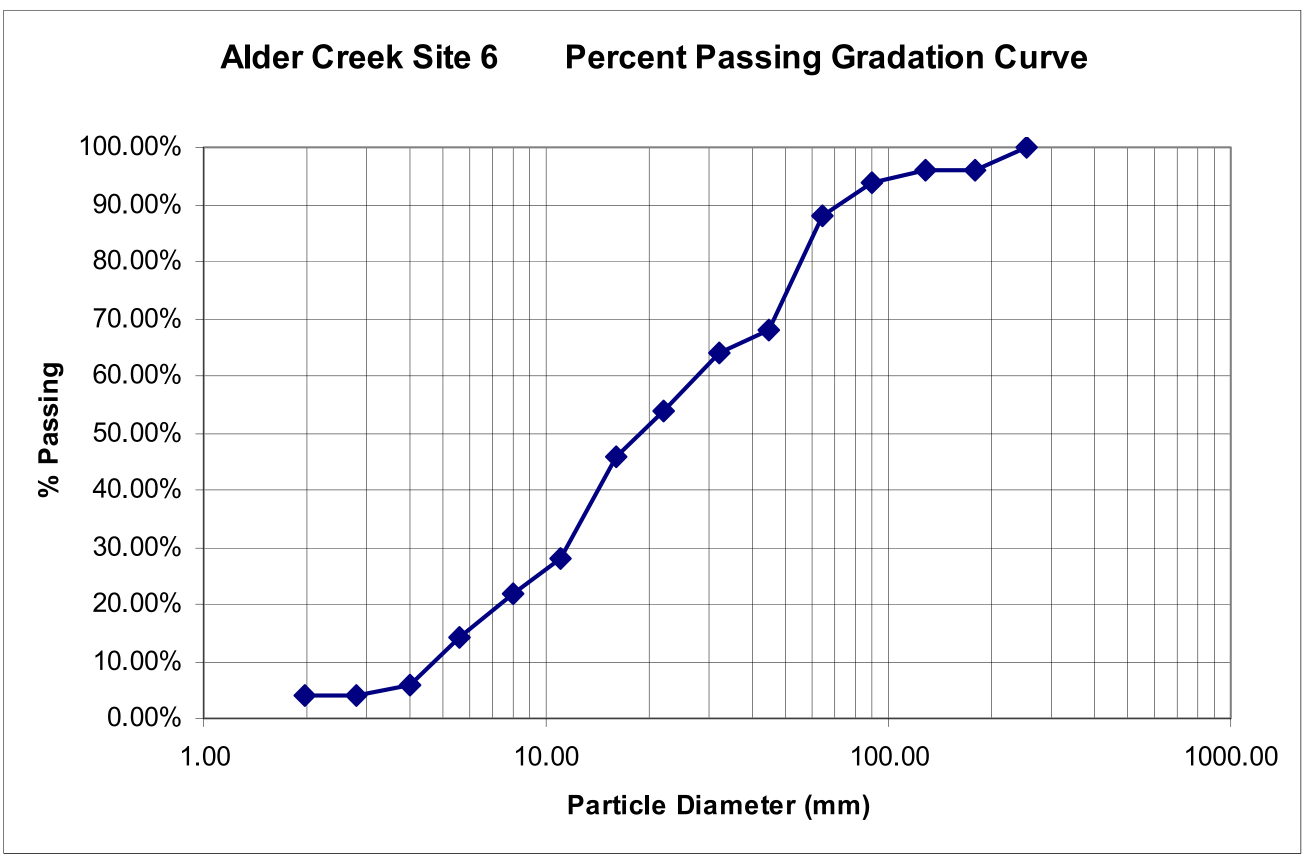
Bed material samples for Sites ECORP-1, 2, 3, 4 and Stagegage collected by ECORP Inc. (Christner, pers. comm.)

Bed material samples were not collected at Sites 3 and 11 but D_{50} estimates were made from field photographs of bed material.

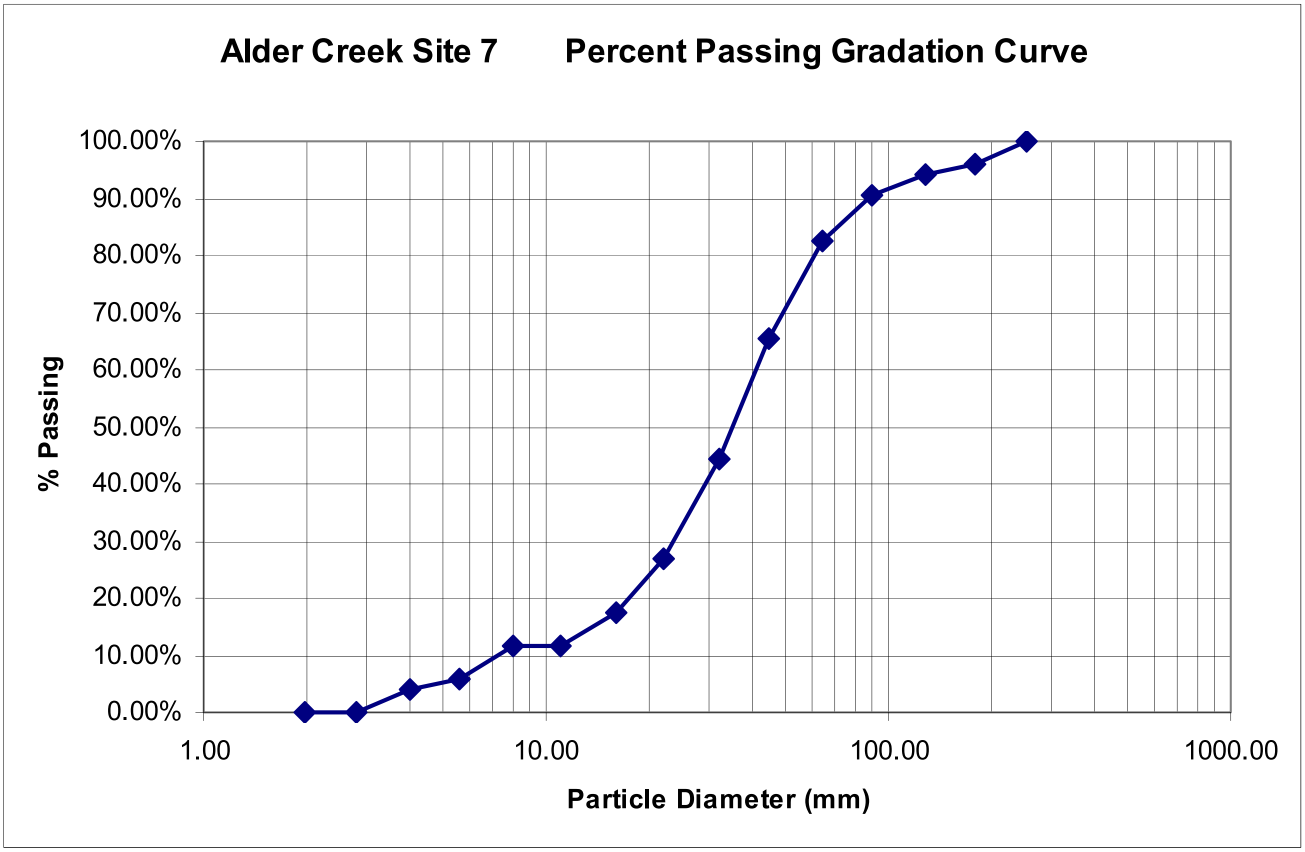
Bed material samples could not be collected at Sites 12, 13, and 14 due to lack of access.

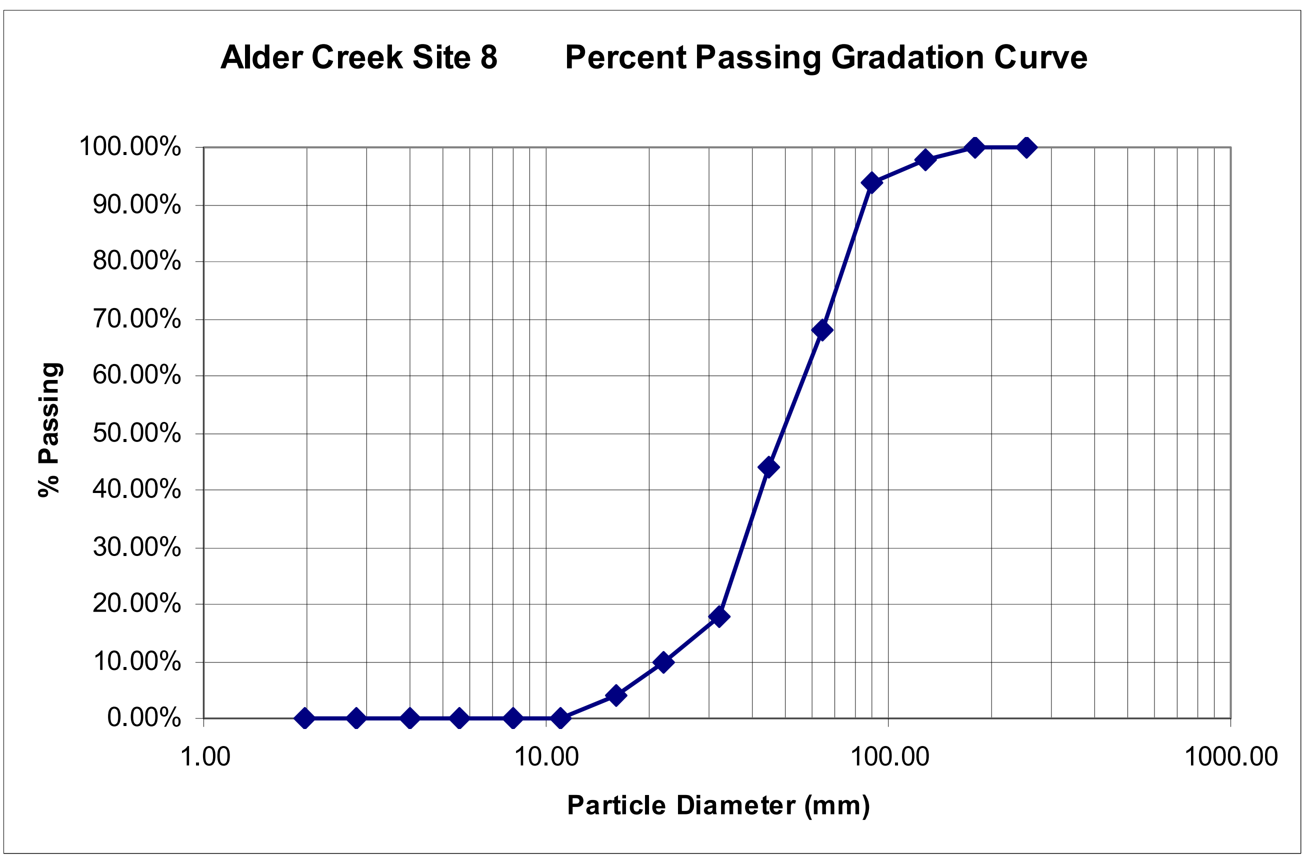


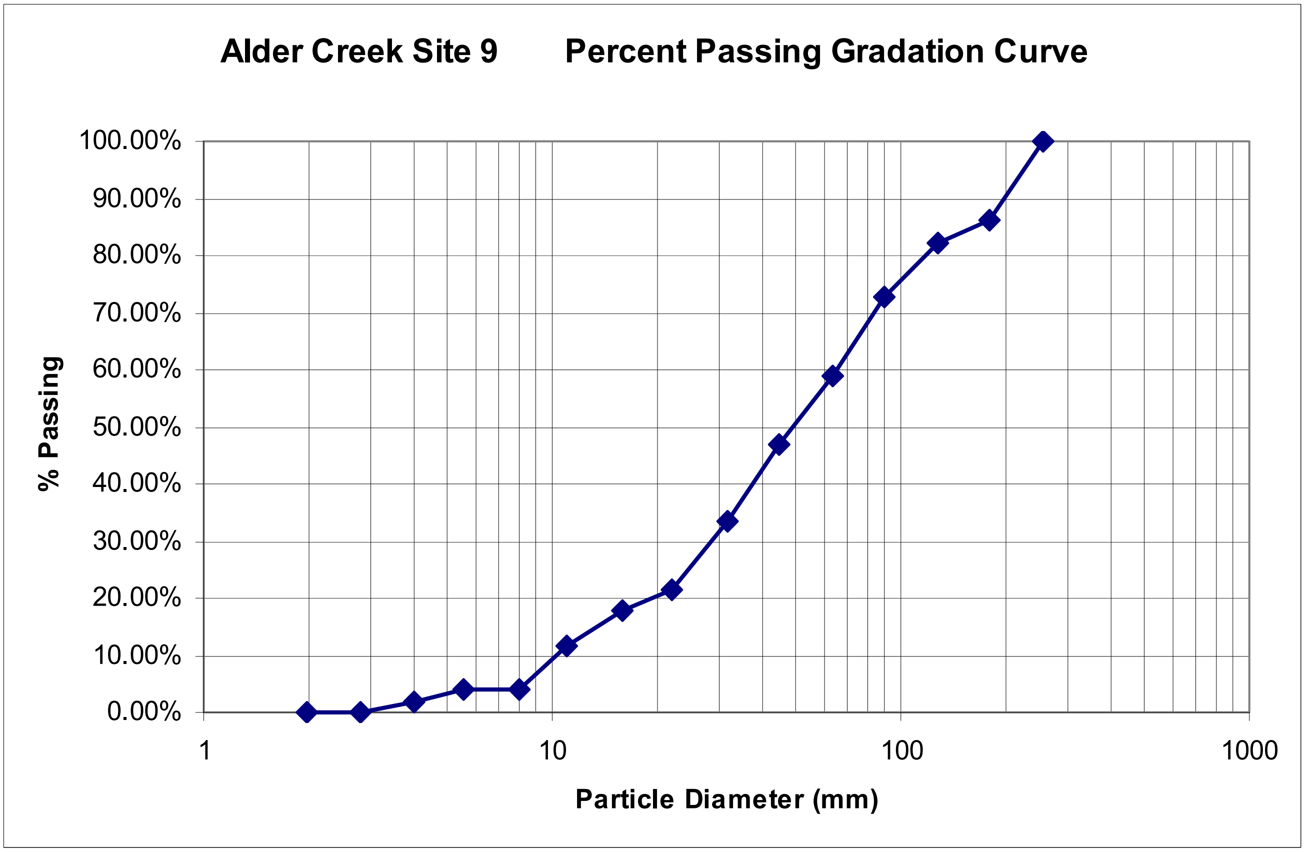
Alder Creek Site 5 Percent Passing Gradation Curve
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
% Passing
1
10
100
1000
Particle Diameter (mm)



Alder Creek Site 6 Percent Passing Gradation Curve
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
% Passing
1.00
10.00
100.00
1000.00
Particle Diameter (mm)

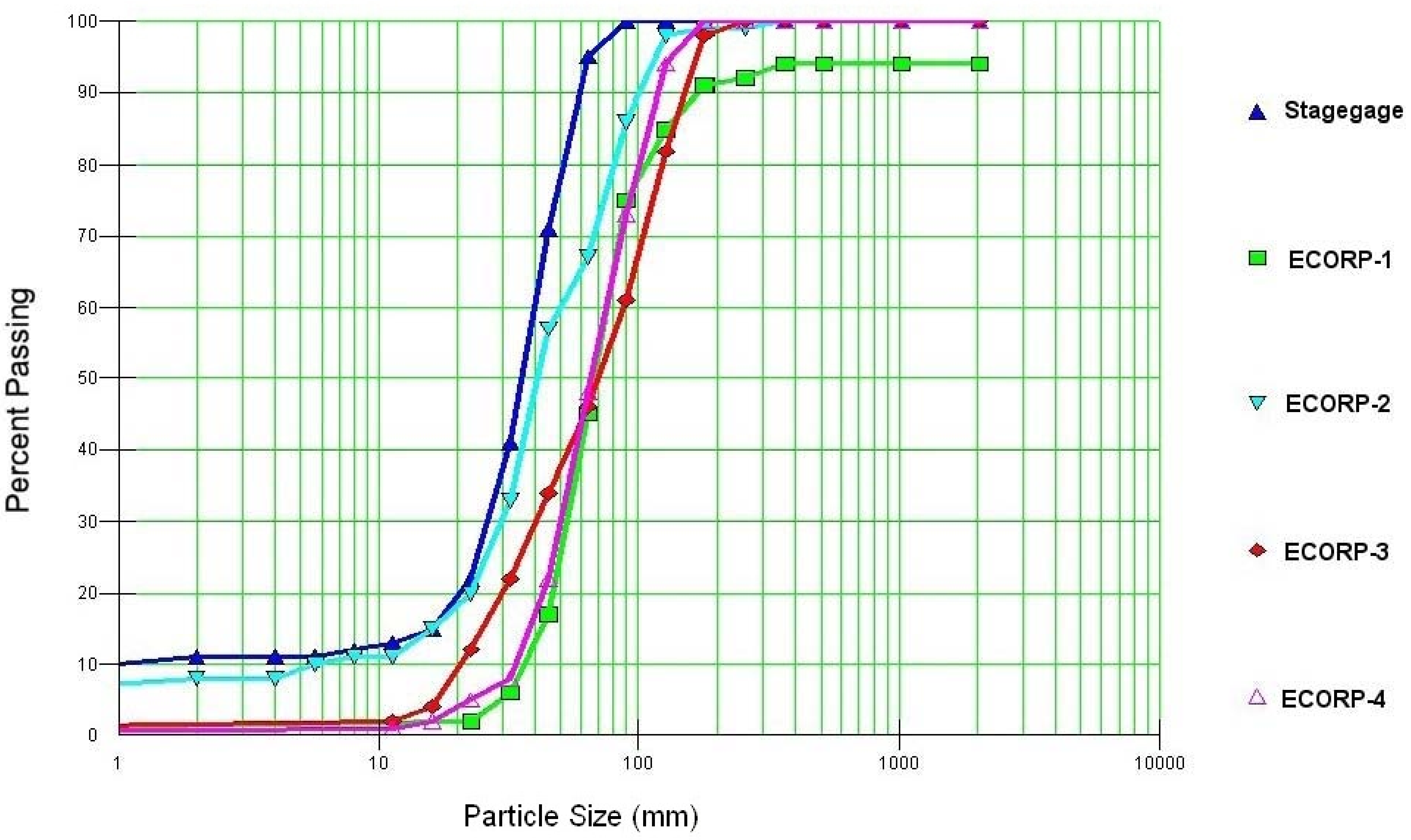

Alder Creek Site 7 Percent Passing Gradation Curve
% Passing
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
1.00
10.00
100.00
1000.00
Particle Diameter (mm)


Alder Creek Site 8 Percent Passing Gradation Curve
% Passing
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
1.00
10.00
100.00
1000.00
Particle Diameter (mm)


Alder Creek Site 9 Percent Passing Gradation Curve
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
% Passing
1
10
100
1000
Particle Diameter (mm)

Particle Size Distributions
Lower Alder Creek

Source: ECORP, Inc. February 8, 2008.



Appendix 1
Field Photos

<u>Notes:</u>

All field photographs taken by **nhc** on February 6th and 7th, 2008.

Site 3 – Looking upstream

Site 3 – Looking upstream at retention pond downstream of Site 3.

Site 5 – Looking upstream

Site 5 – Looking downstream

Site 6 – looking upstream

Site 6 – Looking downstream

Site 7 – Looking downstream

Site 7 – Looking upstream

Site 8 – Looking downstream

Site 8 – Looking downstream

Site 9 – Looking upstream

Site 9 – Looking downstream

Site 11 – Looking upstream

Site 11 – Looking downstream

Site 12 – Looking downstream

Site 13 – Looking downstream

Site 14 – Looking downstream

Site ECORP-1 – Looking downstream

Site ECORP-1 – Looking upstream at Prairie City Road bridge overcrossing

Site ECORP-2 – Looking from left to right bank

Site ECORP-2 – Looking upstream

Site ECORP-3 – Looking downstream

Site ECORP-3 – Looking upstream

Site ECORP-4 – Looking downstream

Site Stagegage – Looking downstream

Site Stagegage – Looking upstream

Appendix 2

Duration Frequency Distributions

Rating Curves

Shear Index Distributions

Appendix 2
Duration Frequency Distributions

<u>Notes:</u>

Duration frequency distributions are generated for geomorphic index points (sites 5, 6, 7, 9, 11, 14, ECORP-2, and Stagegage)

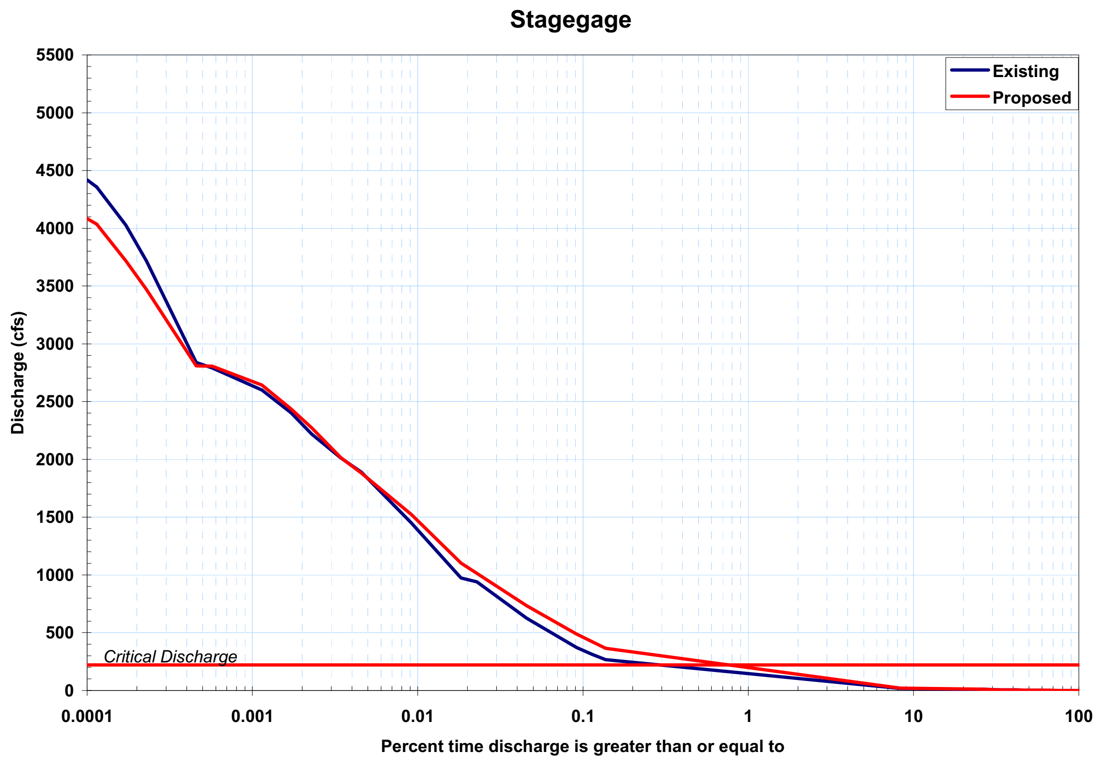


Figure A2. 1: Discharge duration frequency curve at the Stagegage geomorphic index point

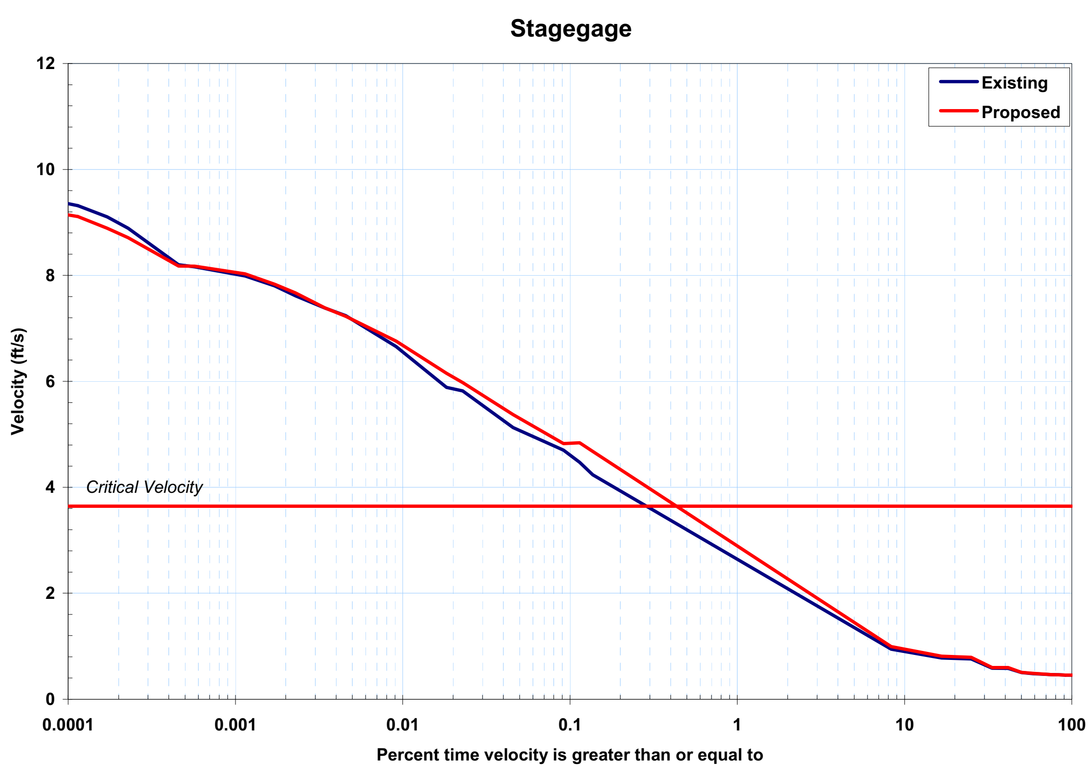


Figure A2. 2: Velocity duration frequency curve at the Stagegage geomorphic index point

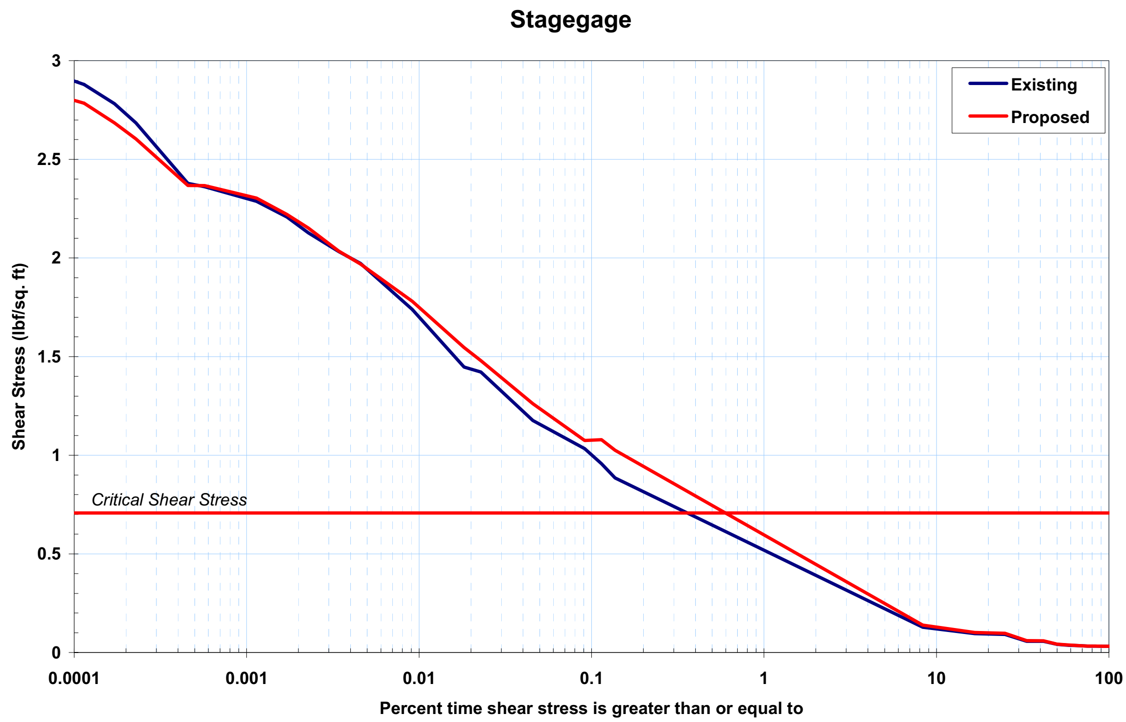


Figure A2. 3: Shear stress duration frequency curve at the Stagegage geomorphic index point

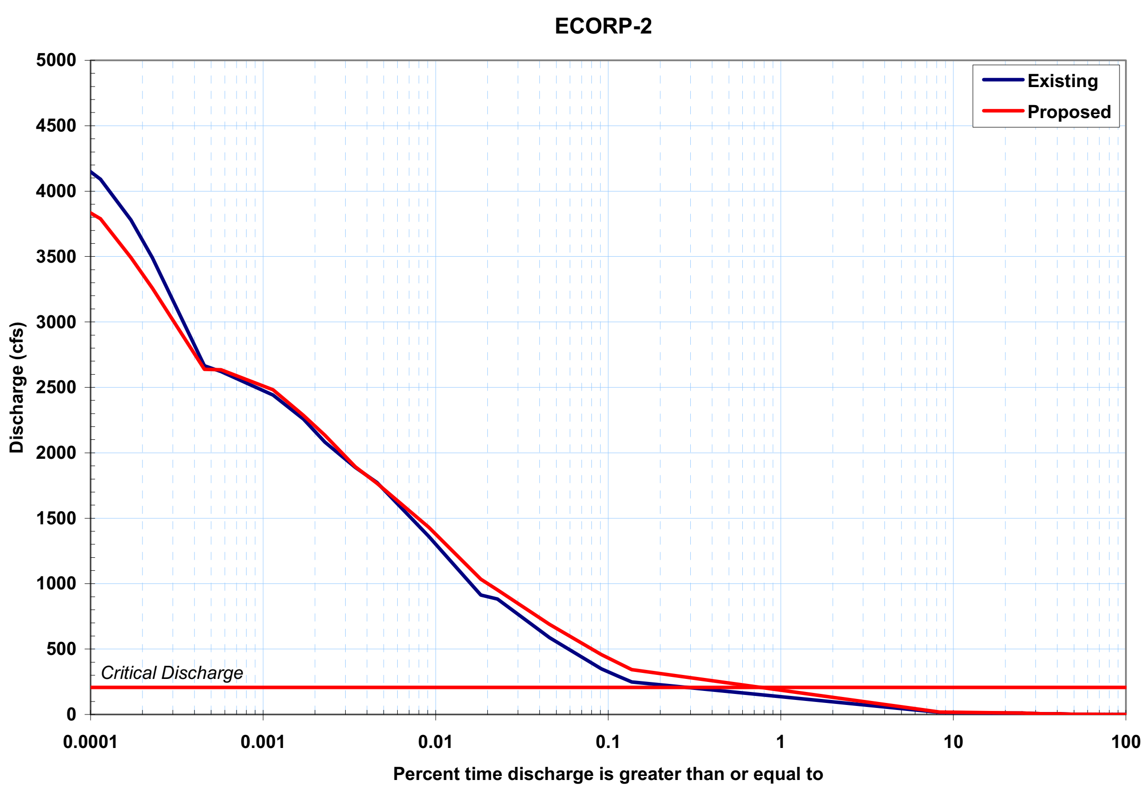


Figure A2. 4: Discharge duration frequency curve at the ECORP-2 geomorphic index point

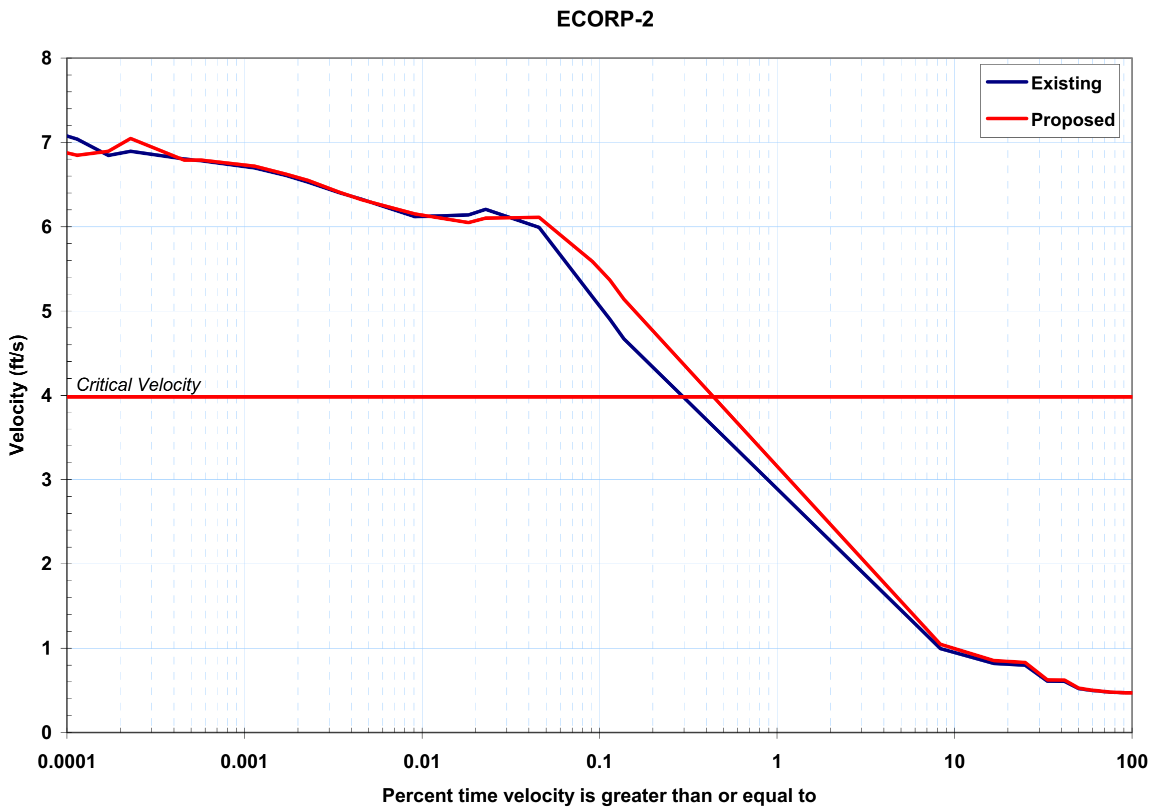


Figure A2. 5: Velocity duration frequency curve at the ECORP-2 geomorphic index point

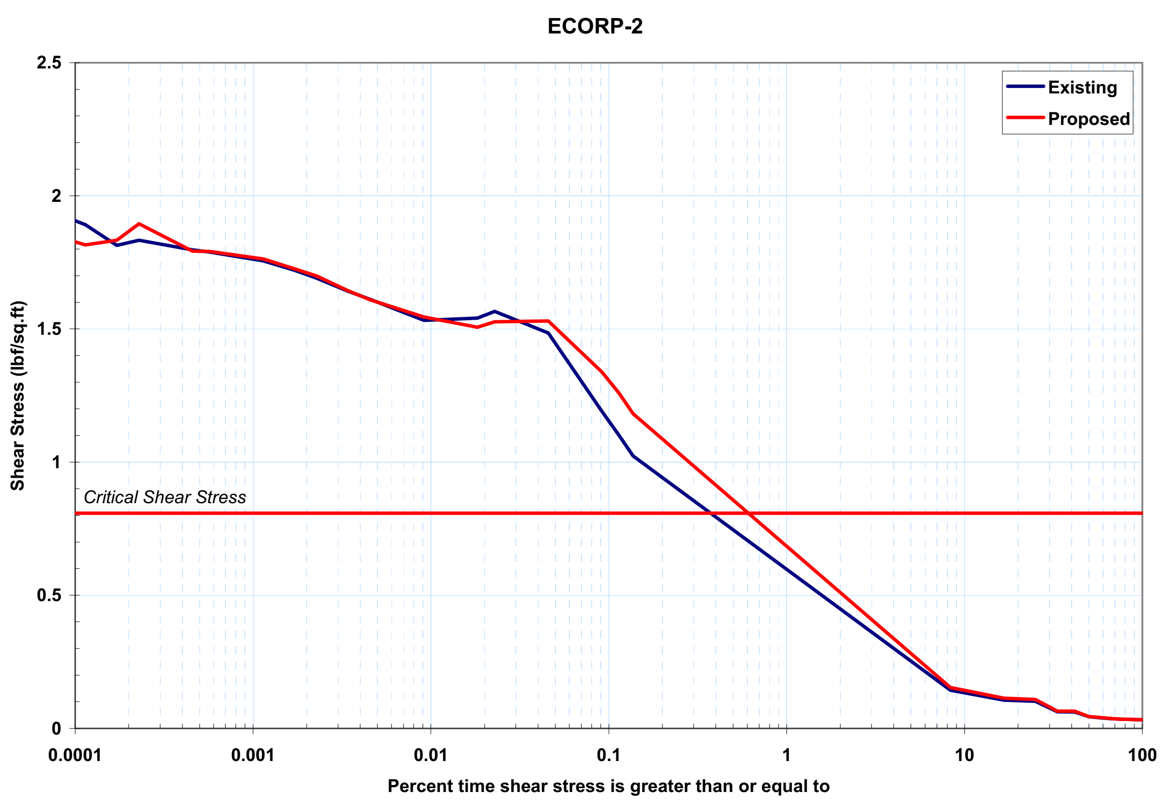


Figure A2. 6: Shear stress duration frequency curve at the ECORP-2 geomorphic index point

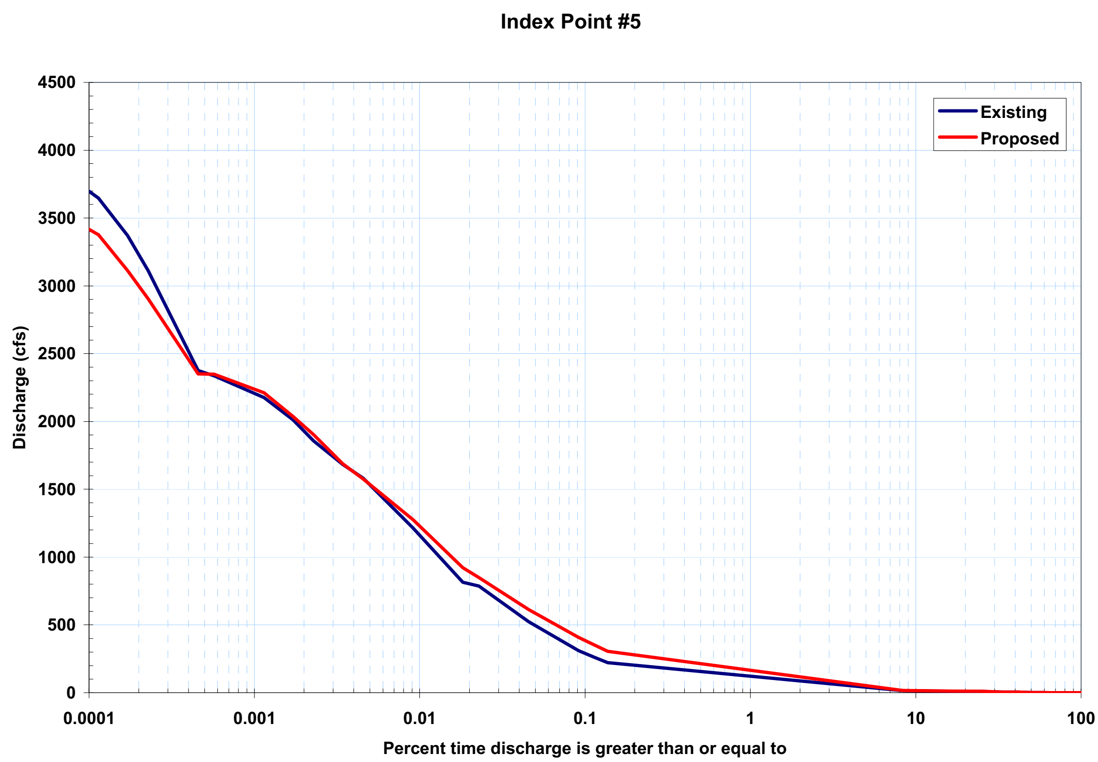


Figure A2. 7: Discharge duration frequency curve at geomorphic index point #5

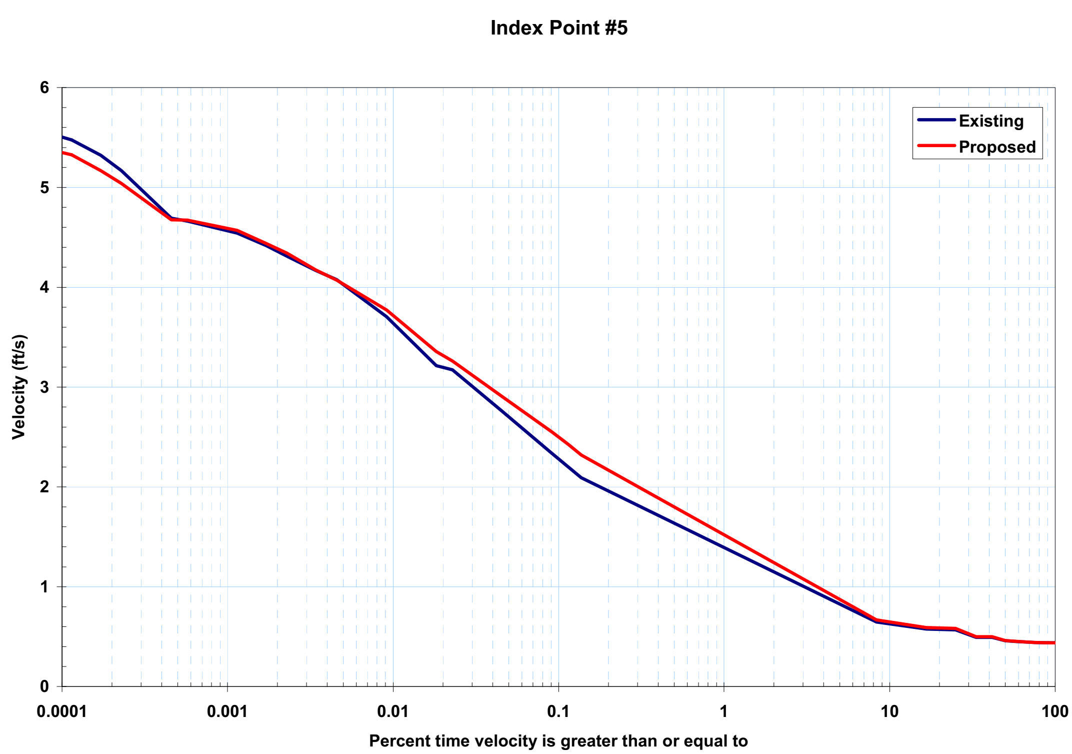


Figure A2. 8: Velocity duration frequency curve at geomorphic index point #5

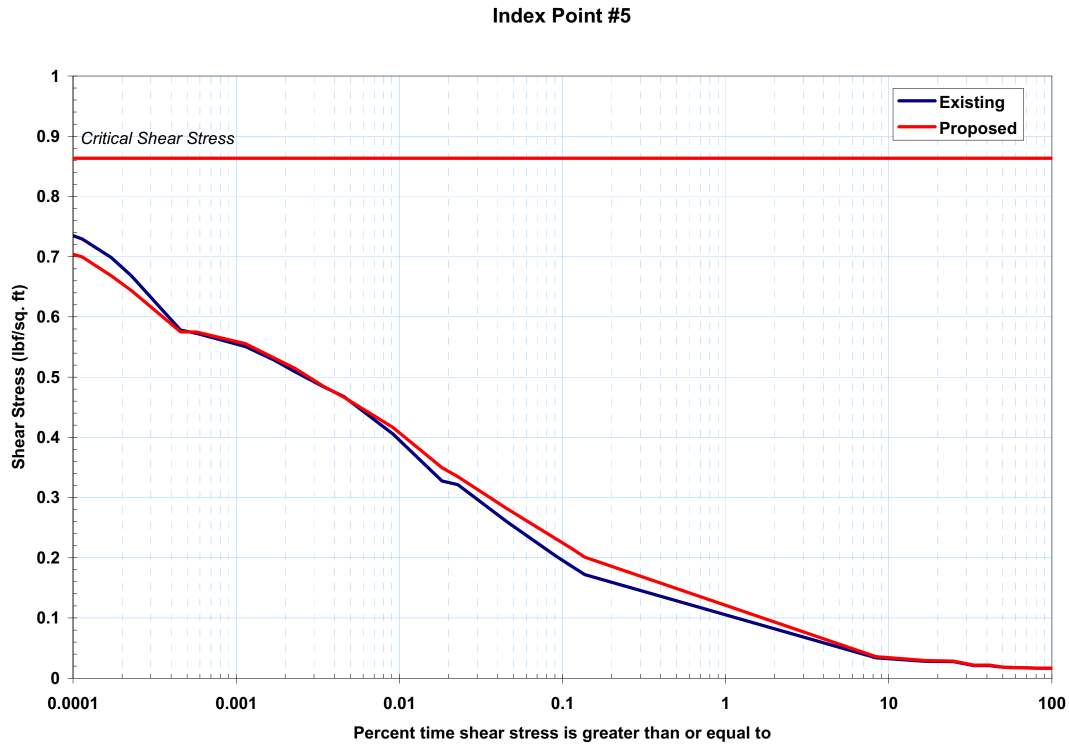


Figure A2. 9: Shear stress duration frequency curve at geomorphic index point #5

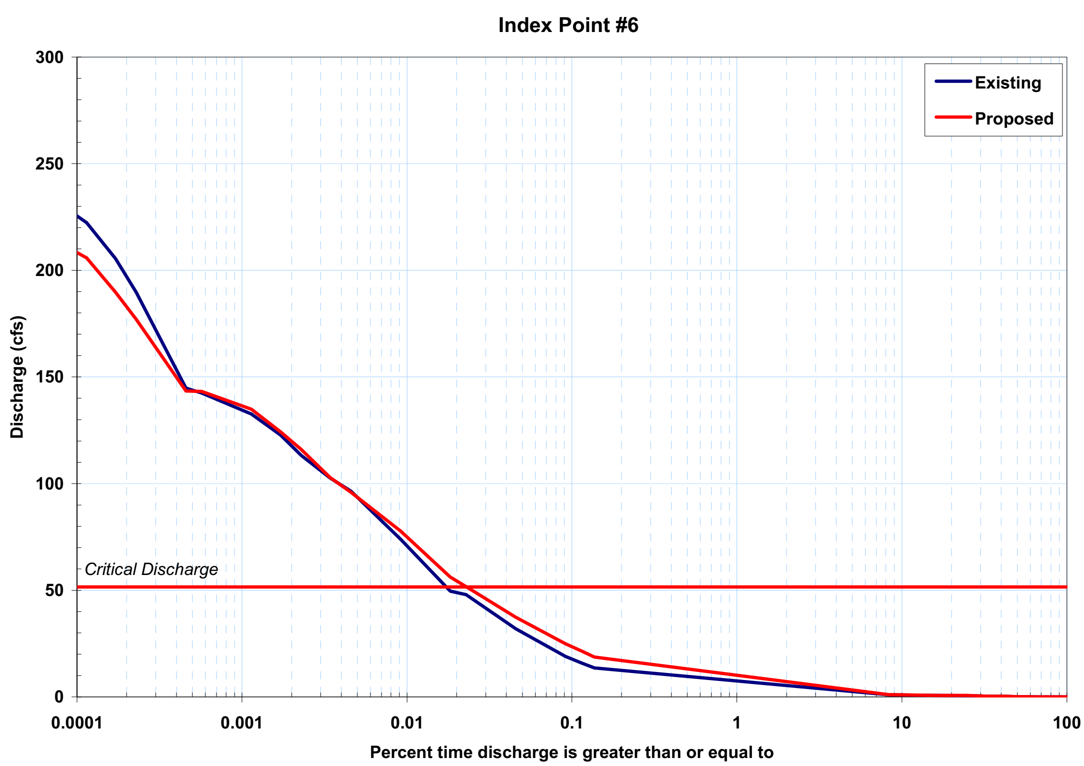


Figure A2. 10: Discharge duration frequency curve at geomorphic index point #6

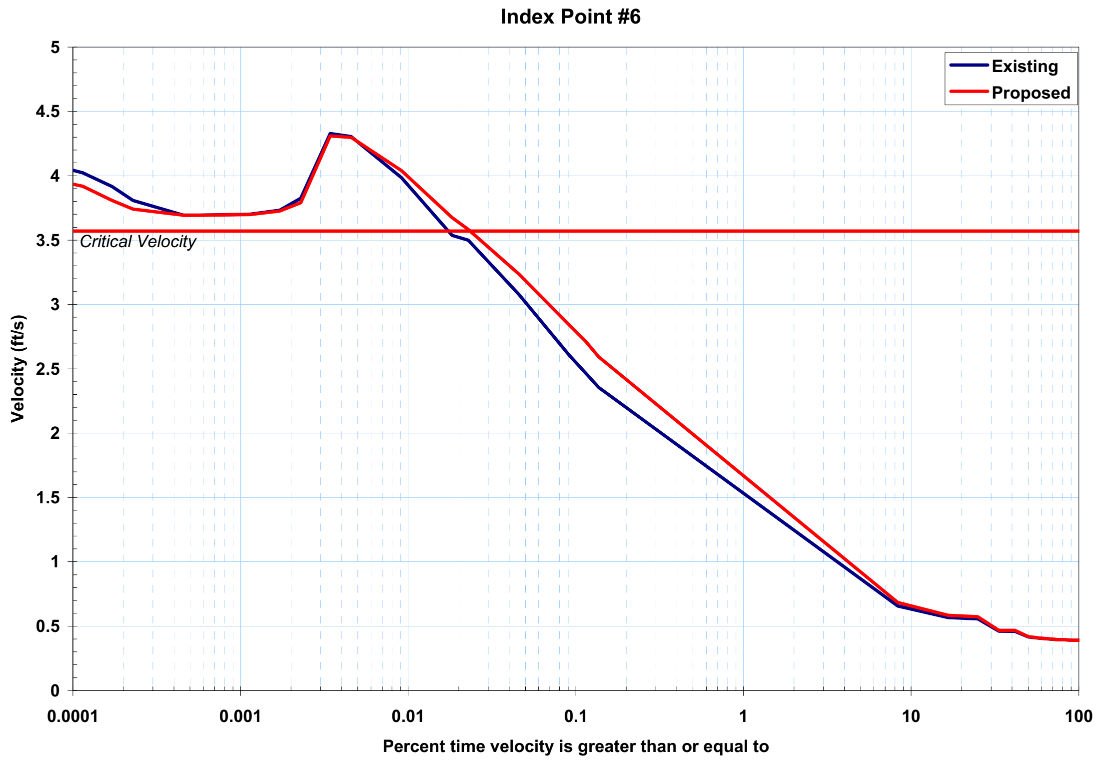


Figure A2. 11: Velocity duration frequency curve at geomorphic index point #6

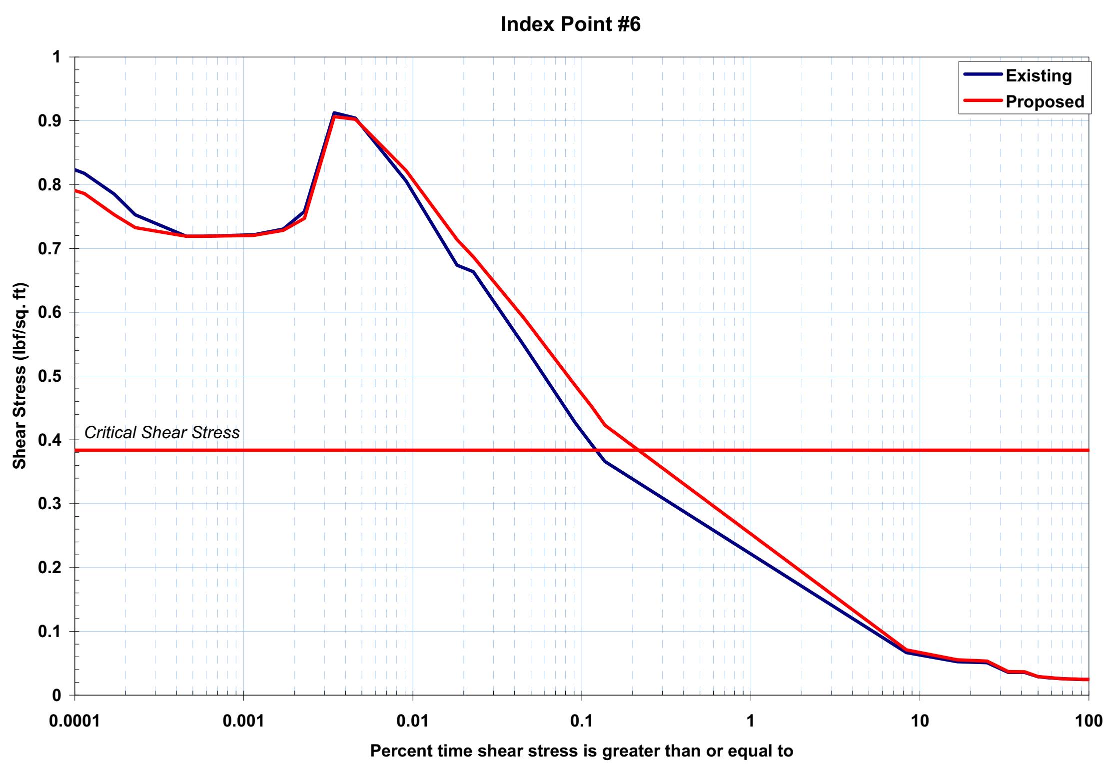


Figure A2. 12: Shear stress duration frequency curve at geomorphic index point #6

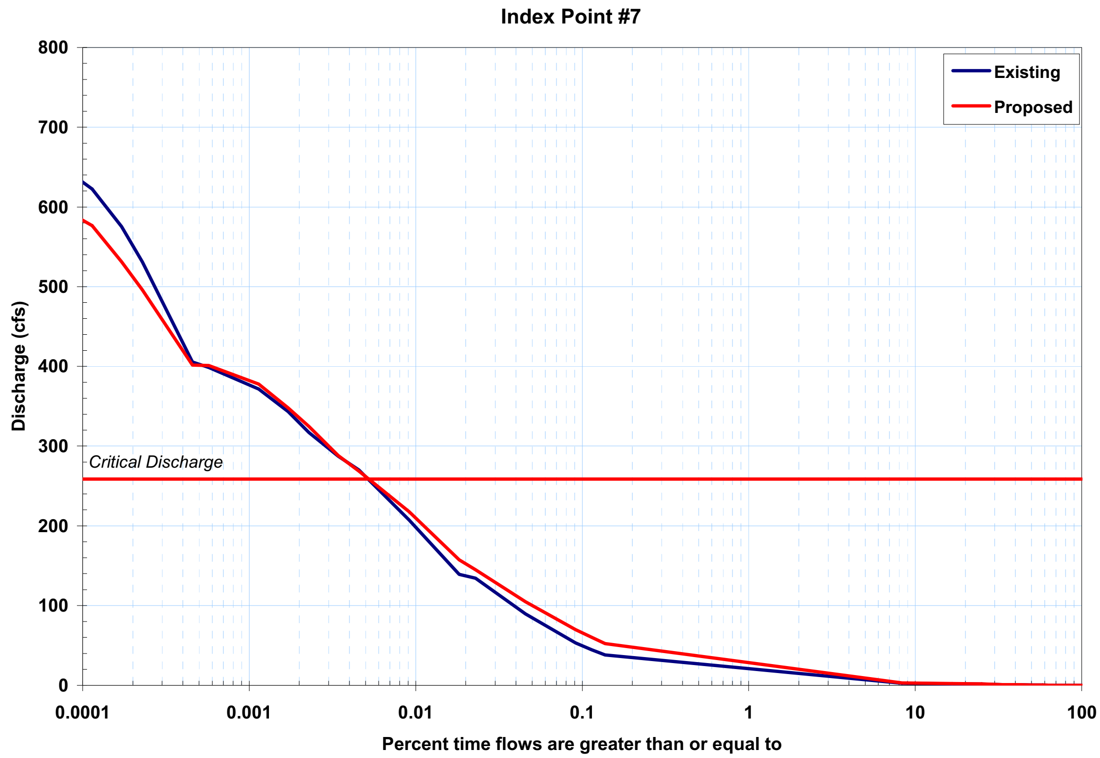


Figure A2. 13: Discharge duration frequency curve at geomorphic index point #7

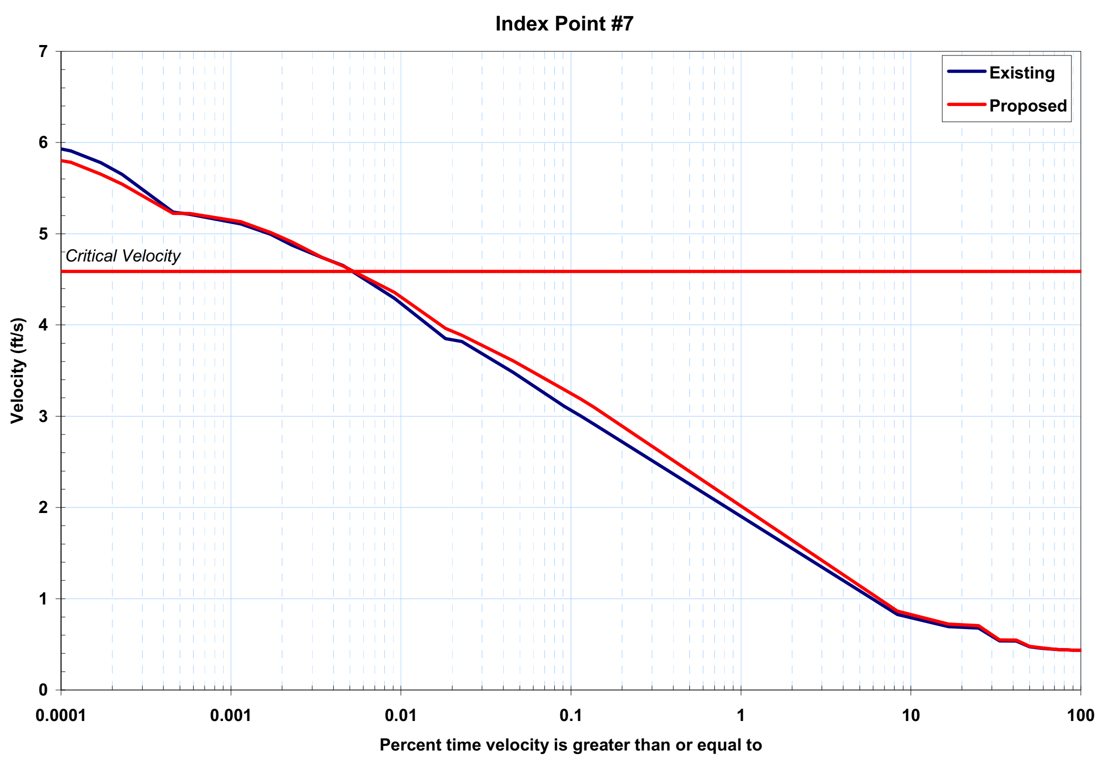


Figure A2. 14: Velocity duration frequency curve at geomorphic index point #7

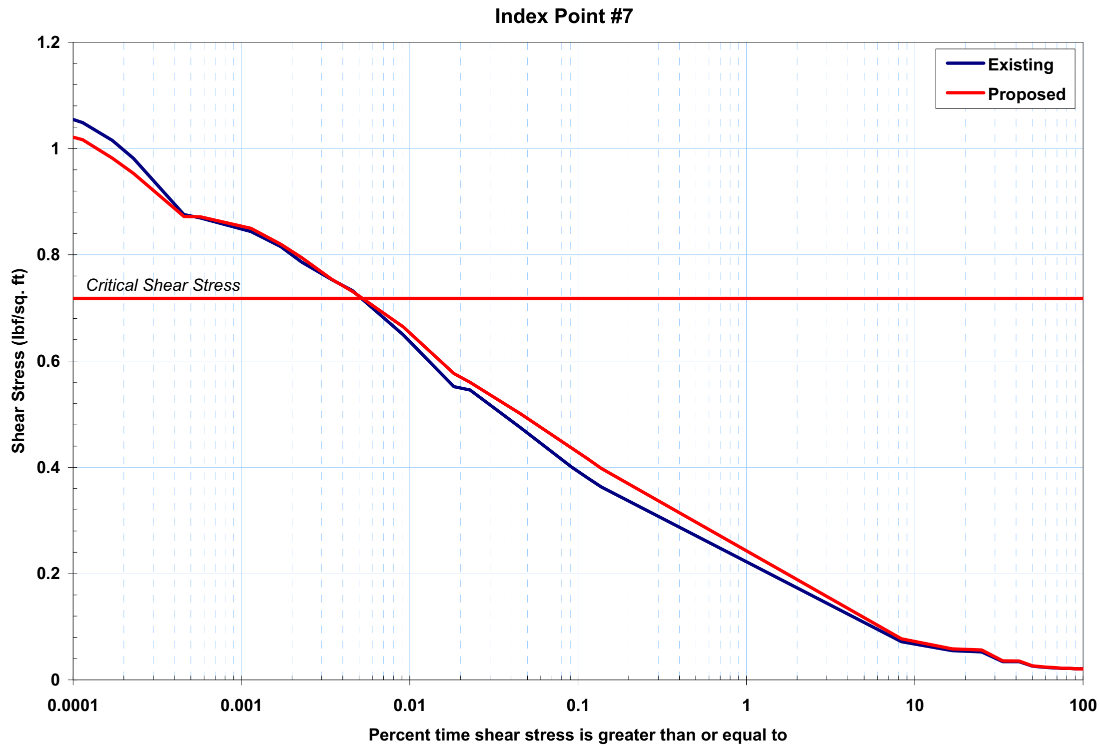


Figure A2. 15: Shear stress duration frequency curve at geomorphic index point #7

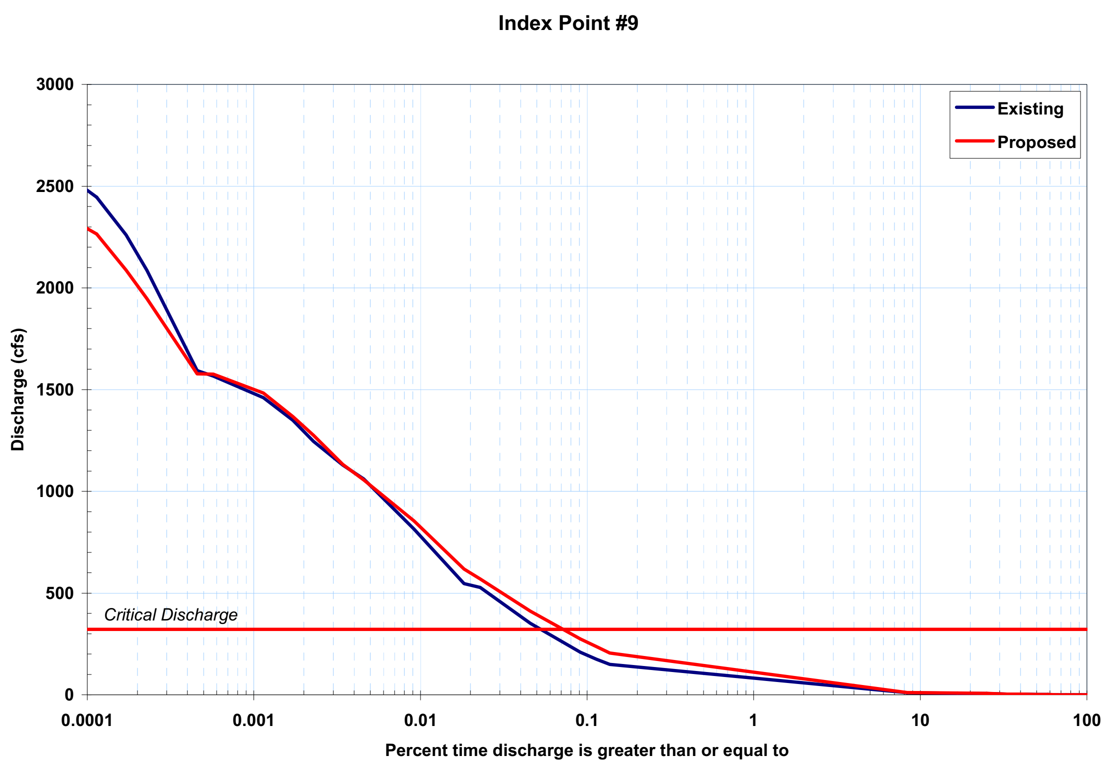


Figure A2. 16: Discharge duration frequency curve at geomorphic index point #9

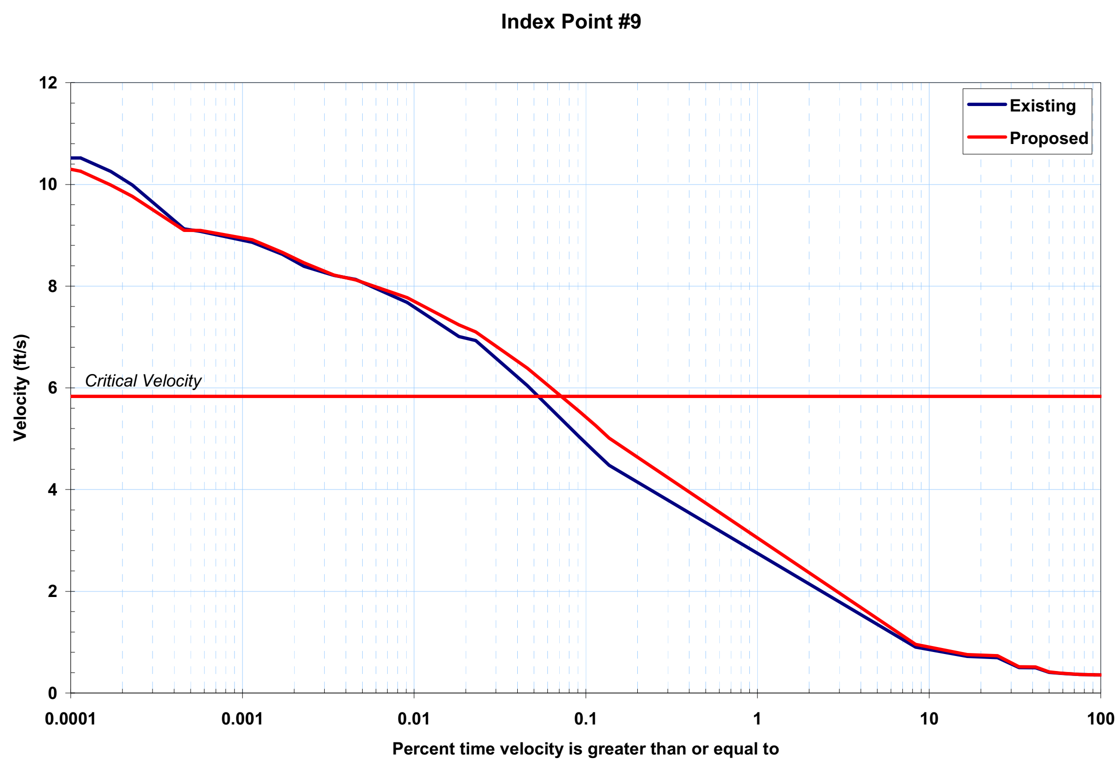


Figure A2. 17: Velocity duration frequency curve at geomorphic index point #9

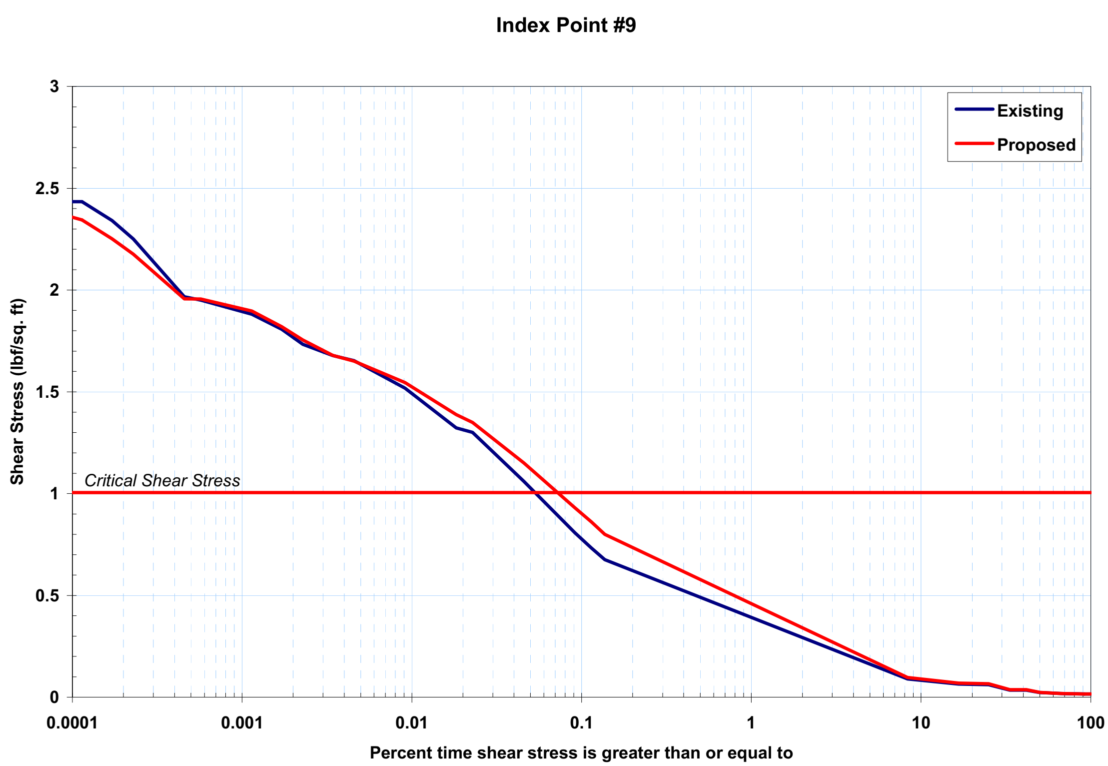


Figure A2. 18: Shear stress duration frequency curve at geomorphic index point #9

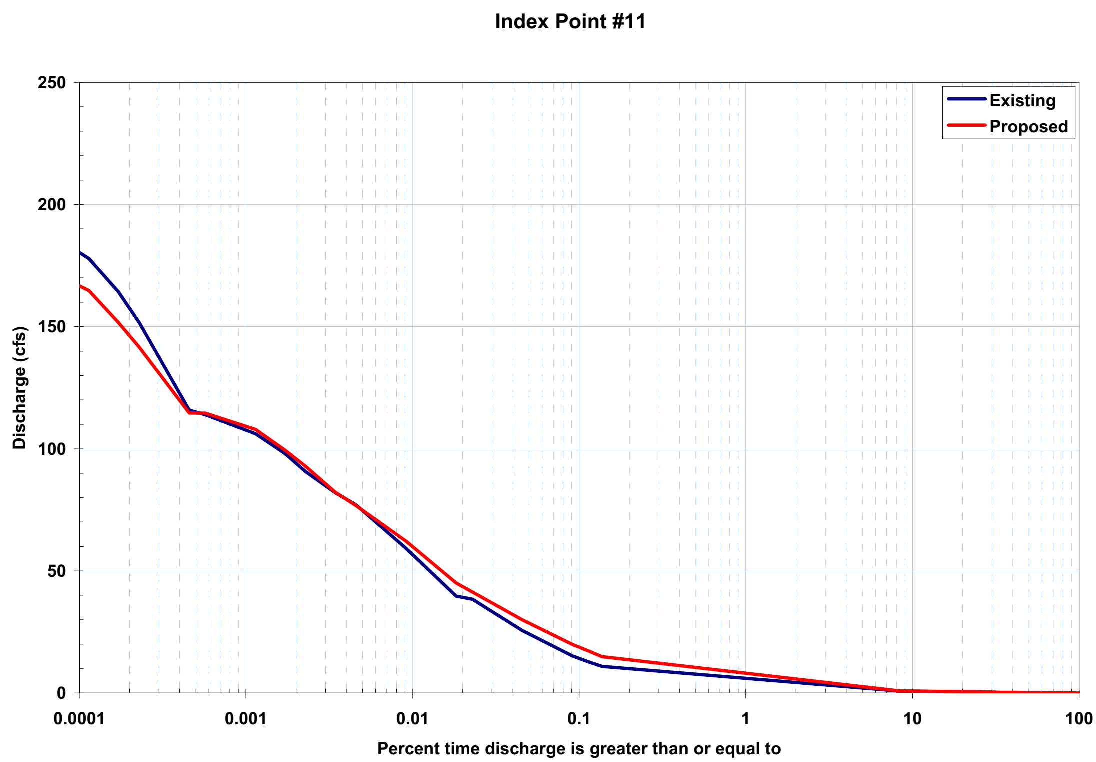


Figure A2. 19: Discharge duration frequency curve at geomorphic index point #11

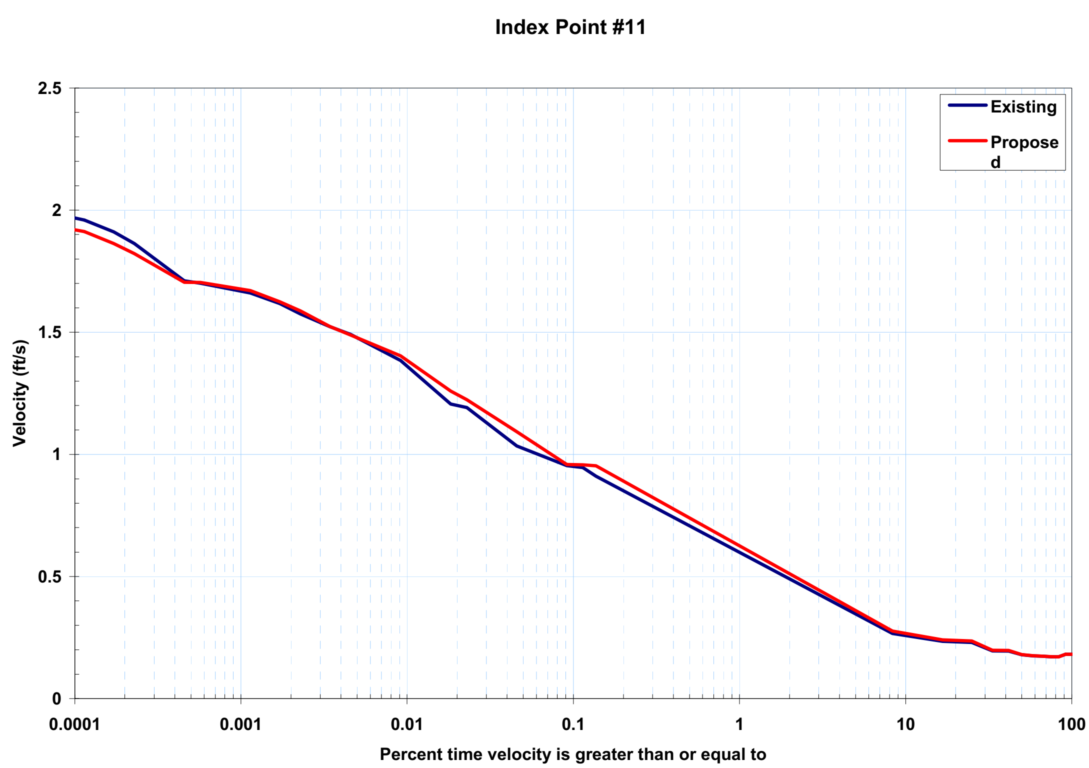


Figure A2. 20: Velocity duration frequency curve at geomorphic index point #11

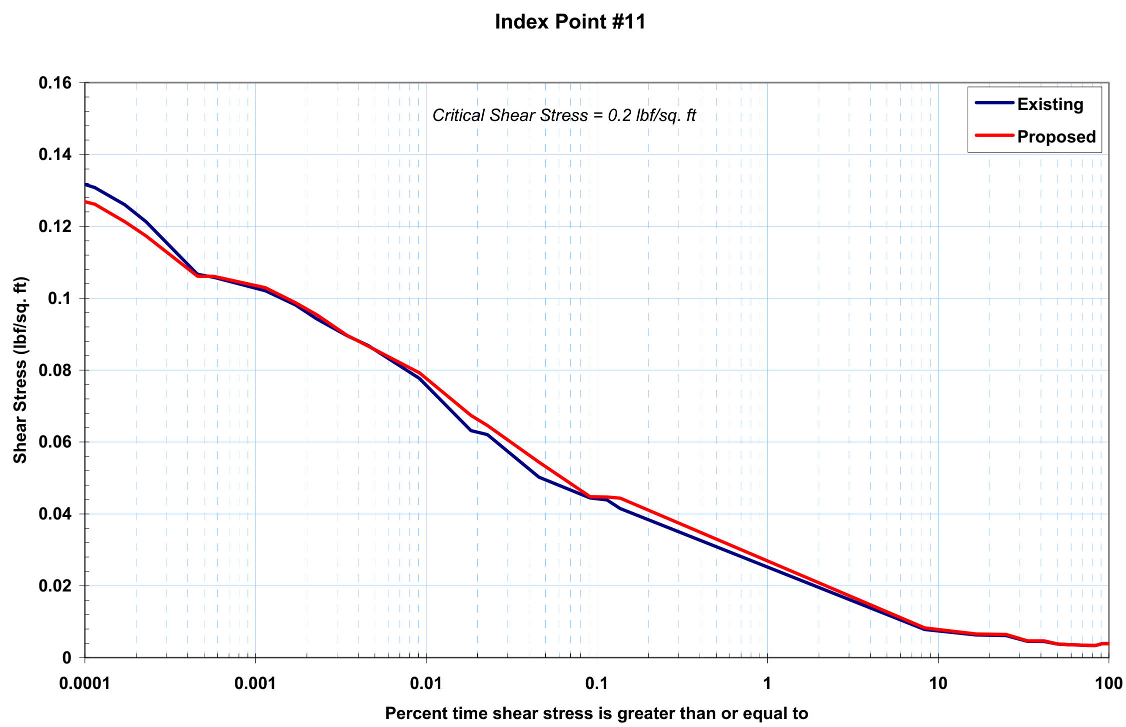


Figure A2. 21: Shear stress duration frequency curve at geomorphic index point #11

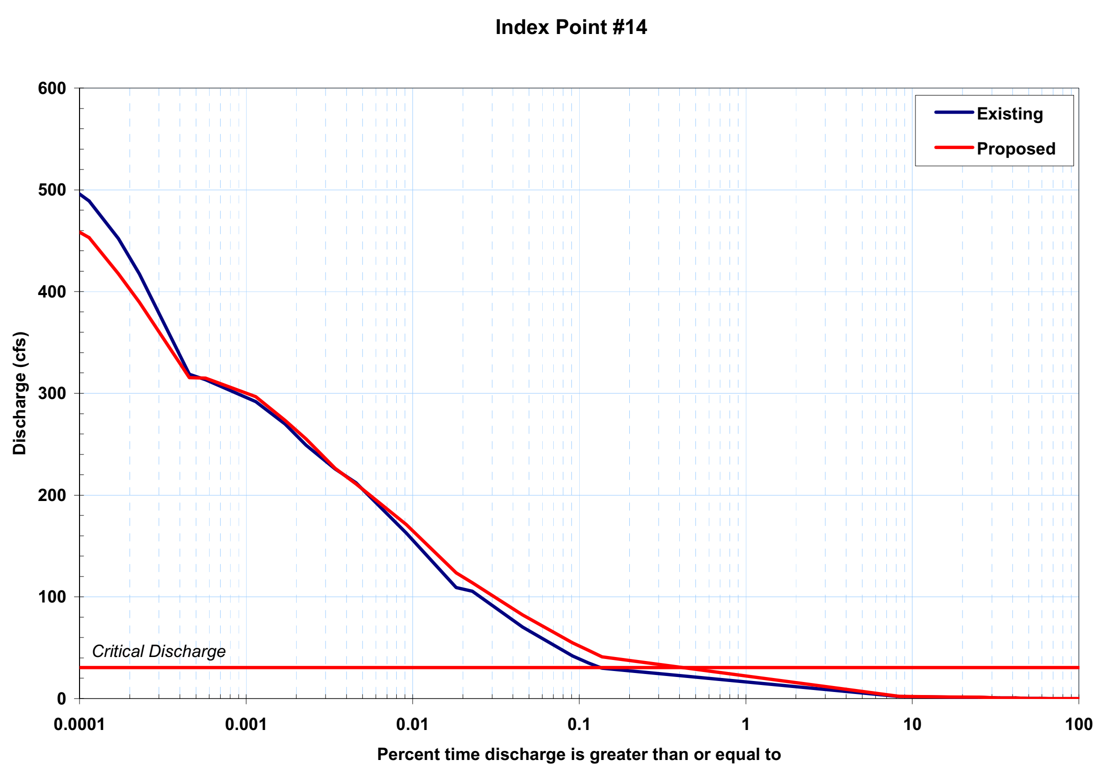


Figure A2. 22: Discharge duration frequency curve at geomorphic index point #14

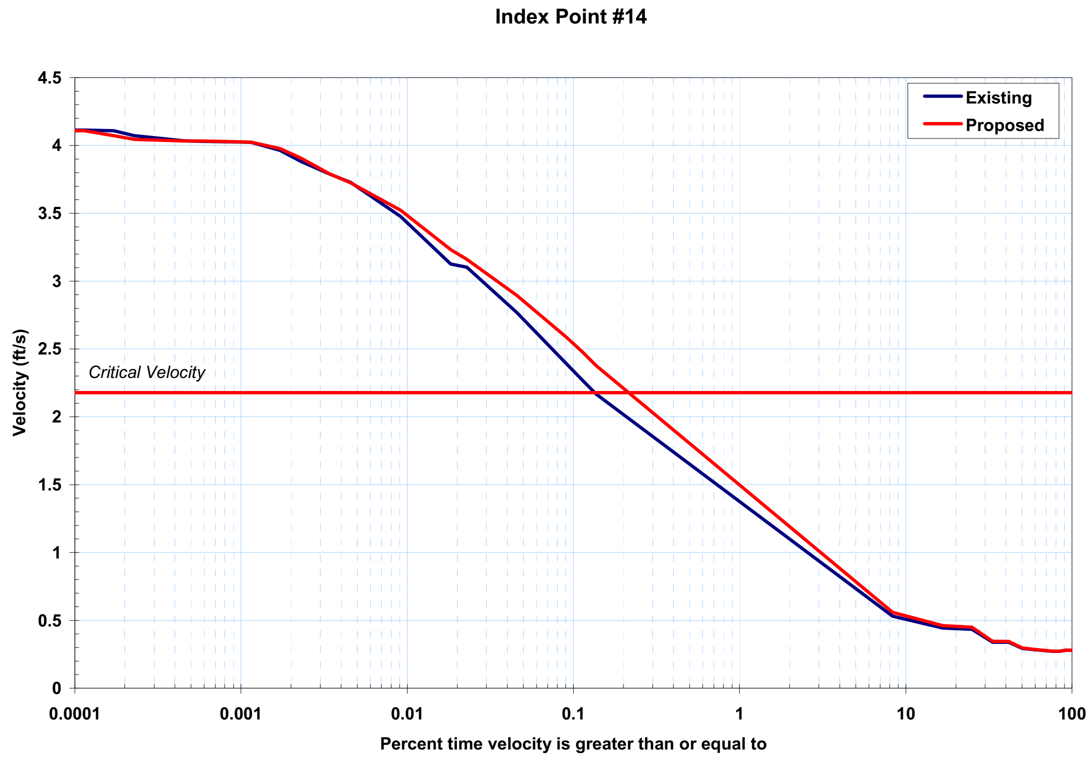


Figure A2. 23: Velocity duration frequency curve at geomorphic index point #14

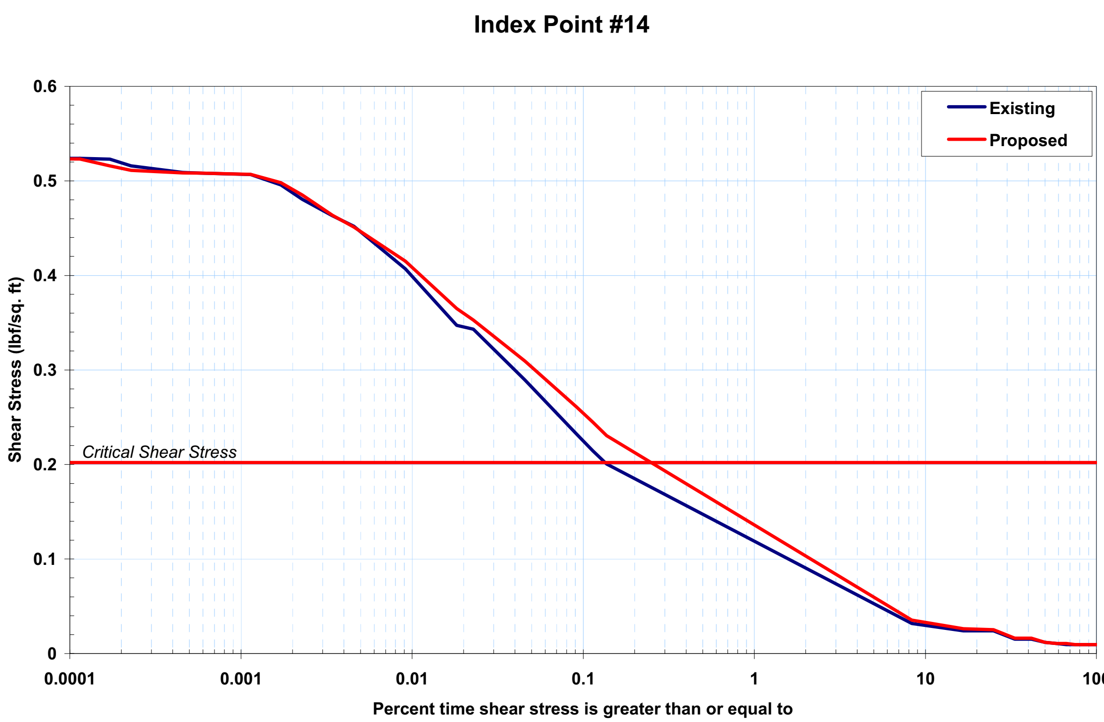


Figure A2. 24: Shear stress duration frequency curve at geomorphic index point #14

Appendix 2
Rating Curves

Notes:

Rating curves are generated for geomorphic index points (sites 5, 6, 7, 9, 11, 14, ECORP-2, and Stagegage)

Rating curve relationships included are discharge versus stage, normal velocity versus stage, and average shear stress versus stage.

Hydrologic inputs for 2, 5, 10, and 100 year flood events are from Domenichelli and Associates (2007).

Hydraulic Inputs for cross sectional geometry, slope, and roughness are generated from data shown in Appendix 1

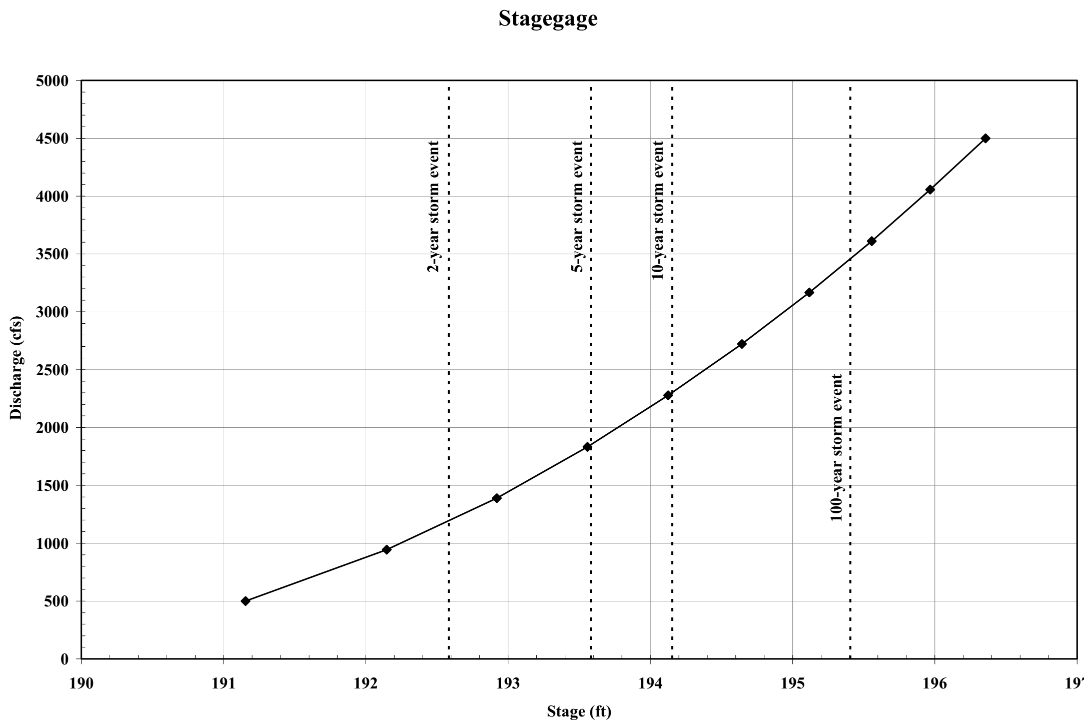


Figure A2. 1: Discharge versus stage relationship for the Stagegage geomorphic index point

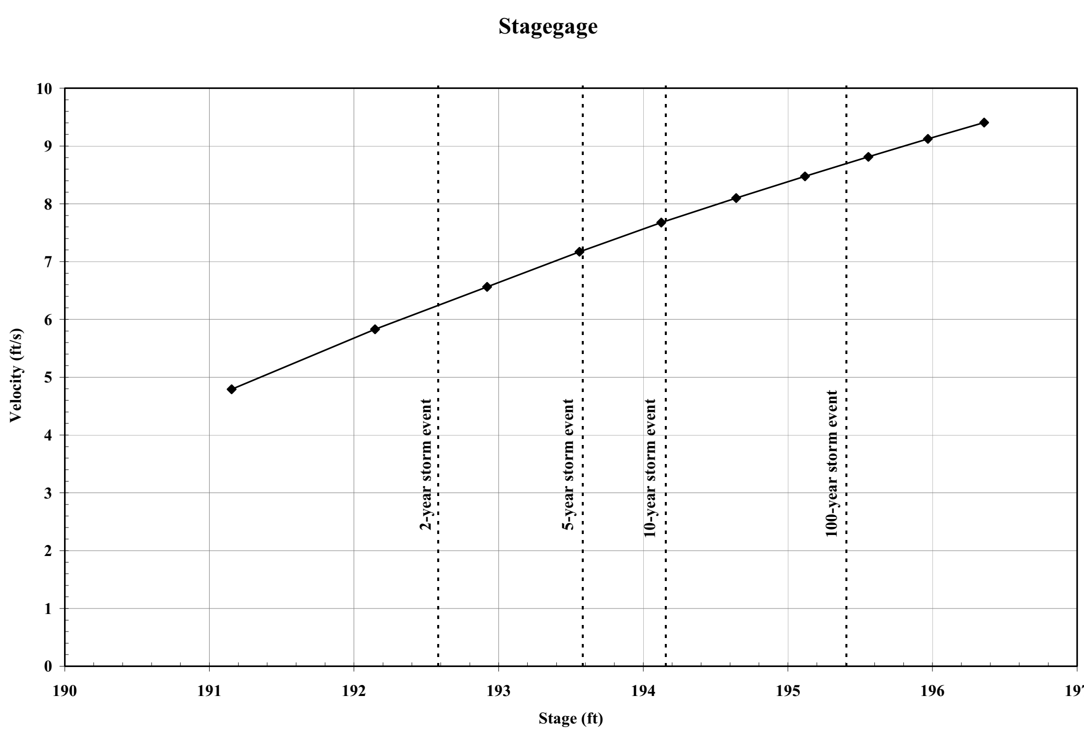


Figure A2. 25: Velocity versus stage relationship for the Stagegage geomorphic index point

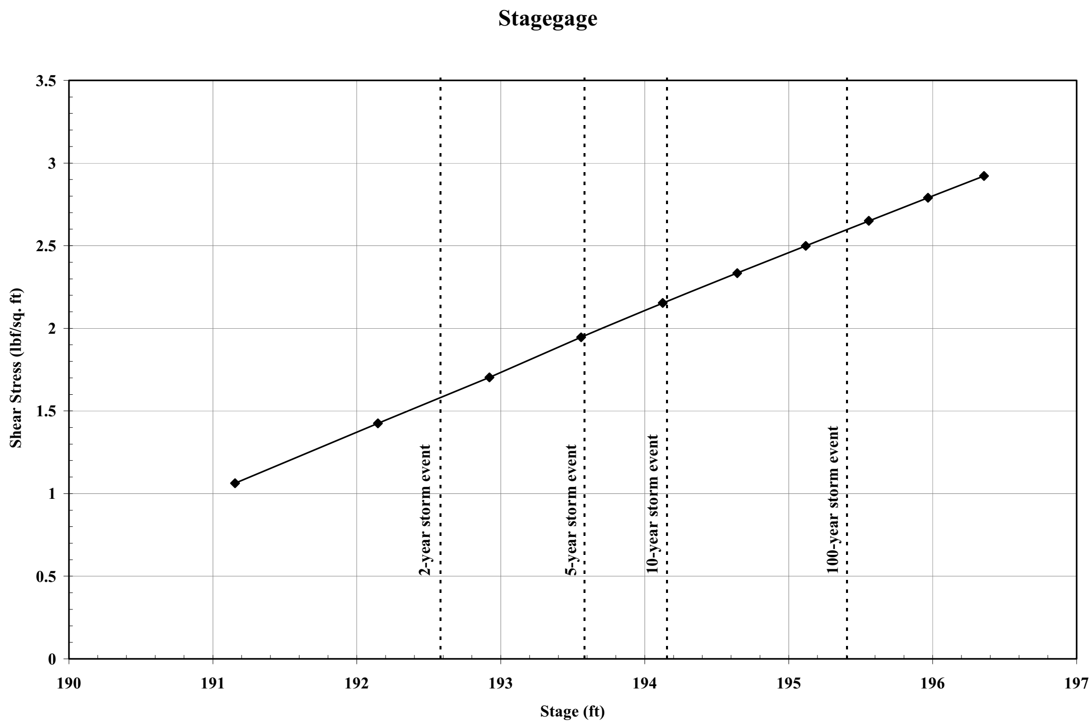


Figure A2. 26: Shear stress versus stage relationship for the Stagegage geomorphic index point

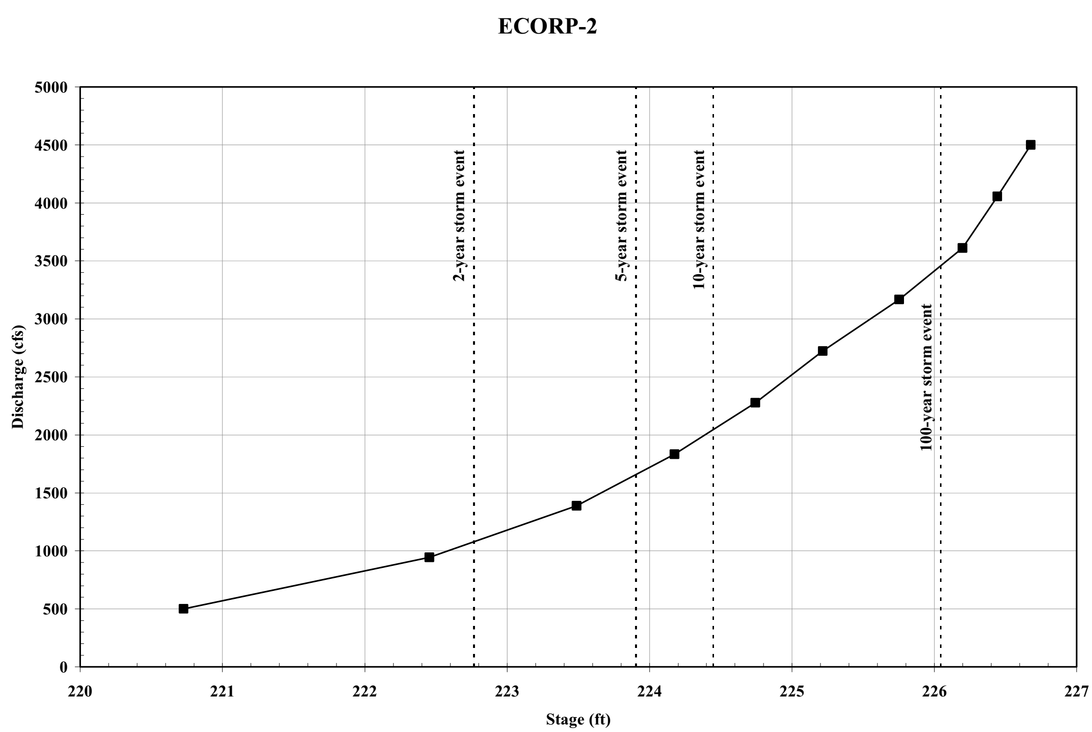


Figure A2. 27: Discharge versus stage relationship for the ECORP-2 cross section geomorphic index point

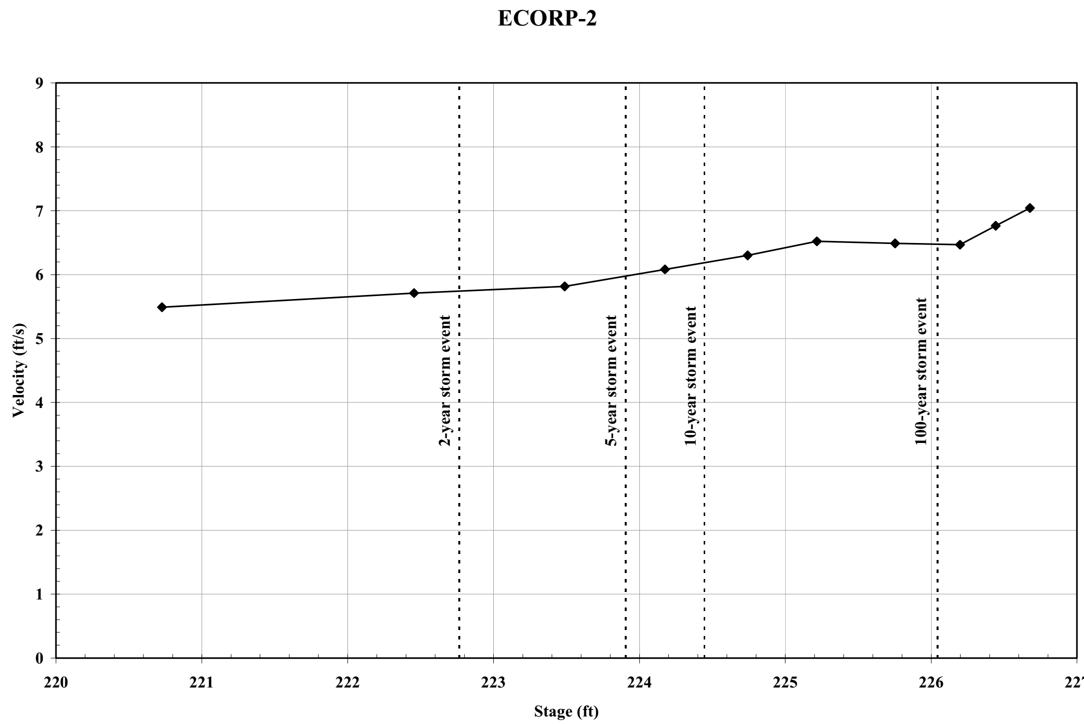


Figure A2. 28: Velocity versus stage relationship for the ECORP-2 cross section geomorphic index point

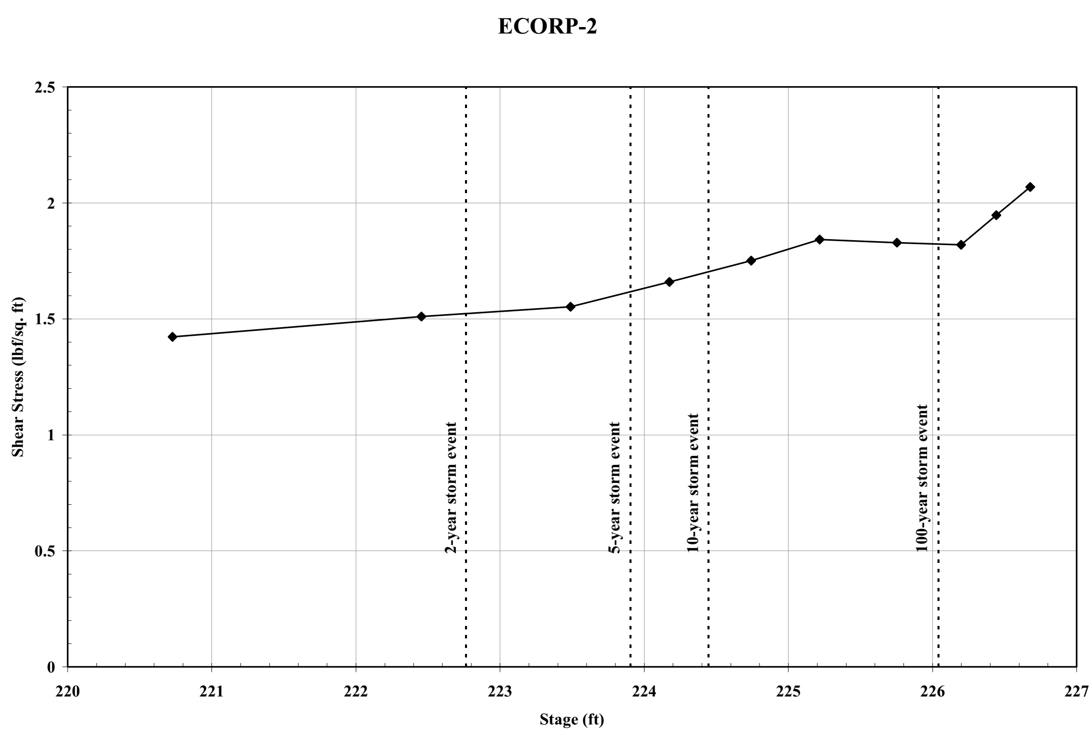


Figure A2. 29: Shear stress versus stage relationship for the ECORP-2 cross section geomorphic index point

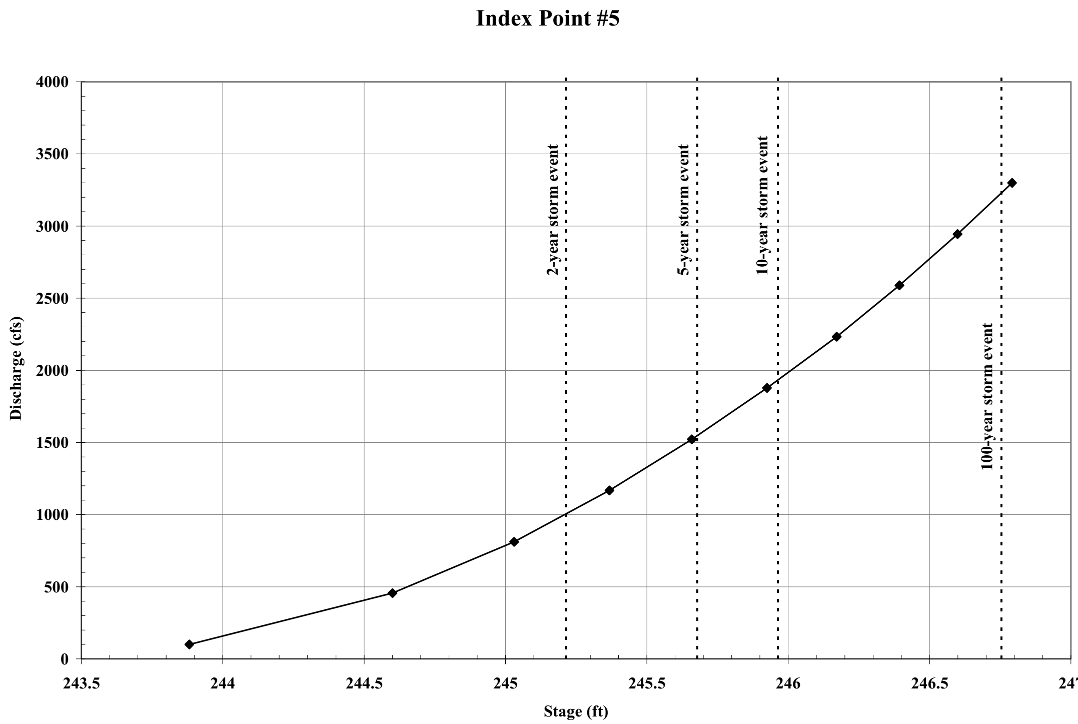


Figure A2. 30: Discharge versus stage relationship for geomorphic index point #5

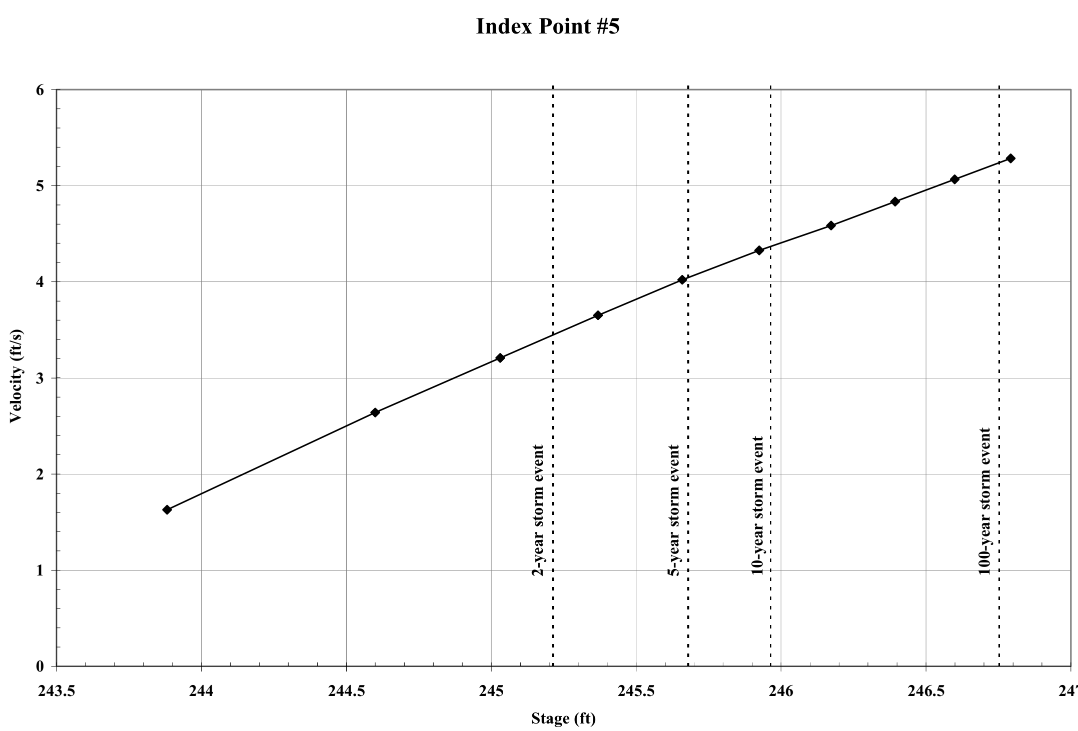


Figure A2. 31: Velocity versus stage relationship for geomorphic index point #5

Index Point #5

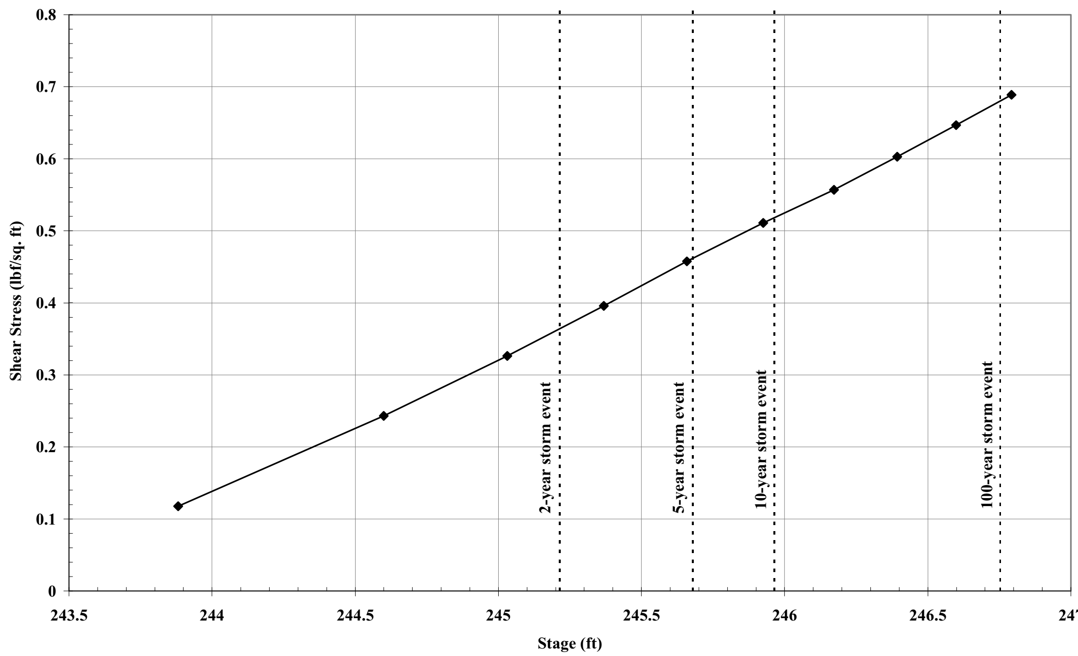


Figure A2. 32: Shear stress versus stage relationship for geomorphic index point #5

Index Point #6

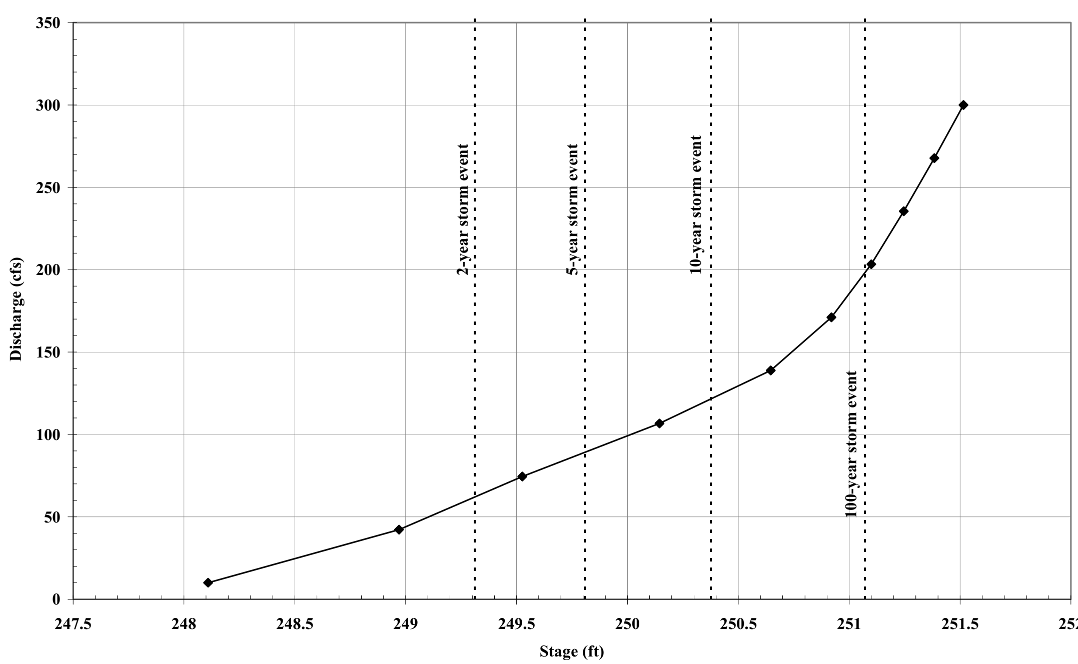


Figure A2. 33: Discharge versus stage relationship for geomorphic index point #6

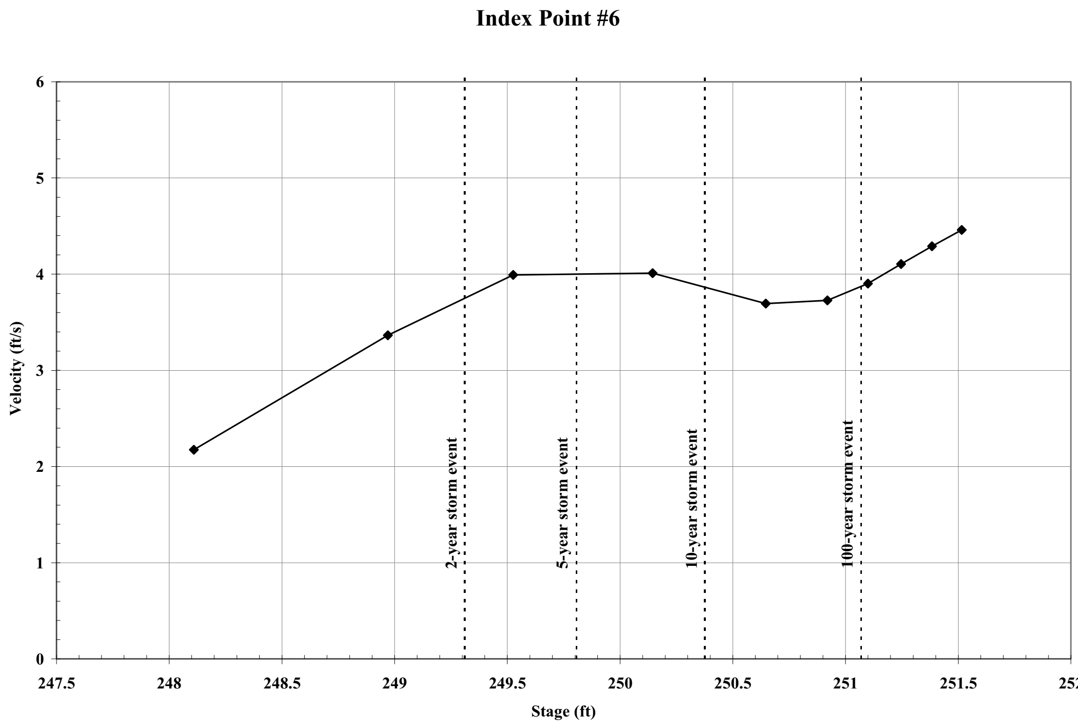


Figure A2. 34: Velocity versus stage relationship for geomorphic index point #6

.

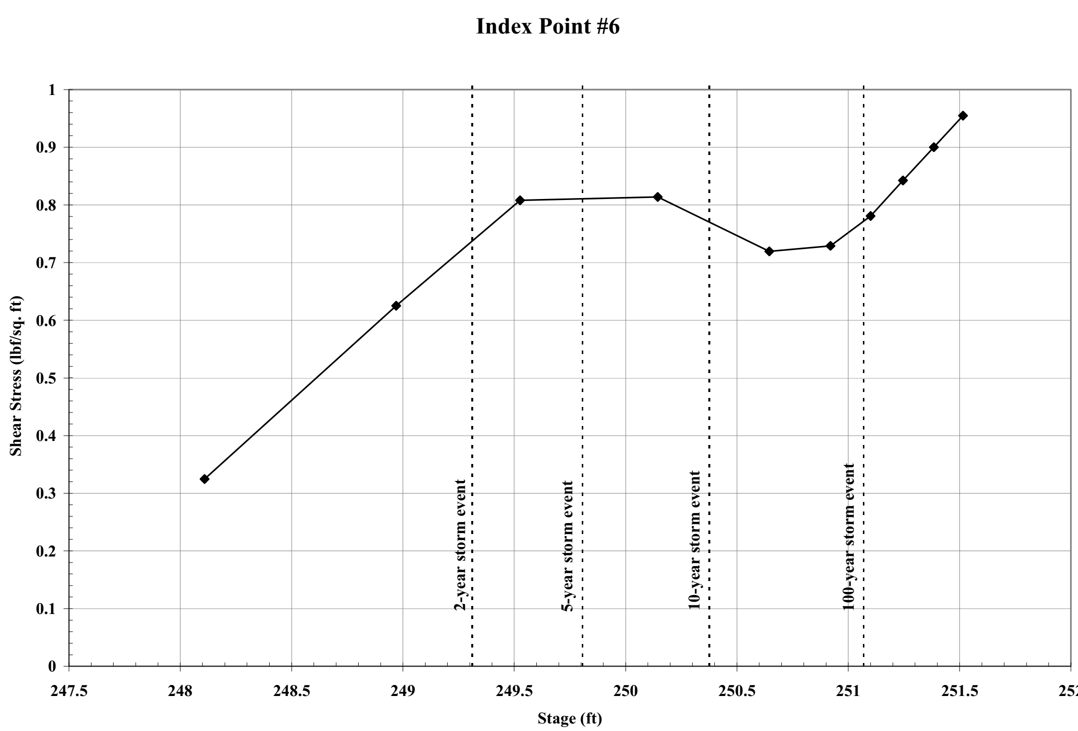


Figure A2. 35: Shear stress versus stage relationship for geomorphic index point #6

Index Point #7

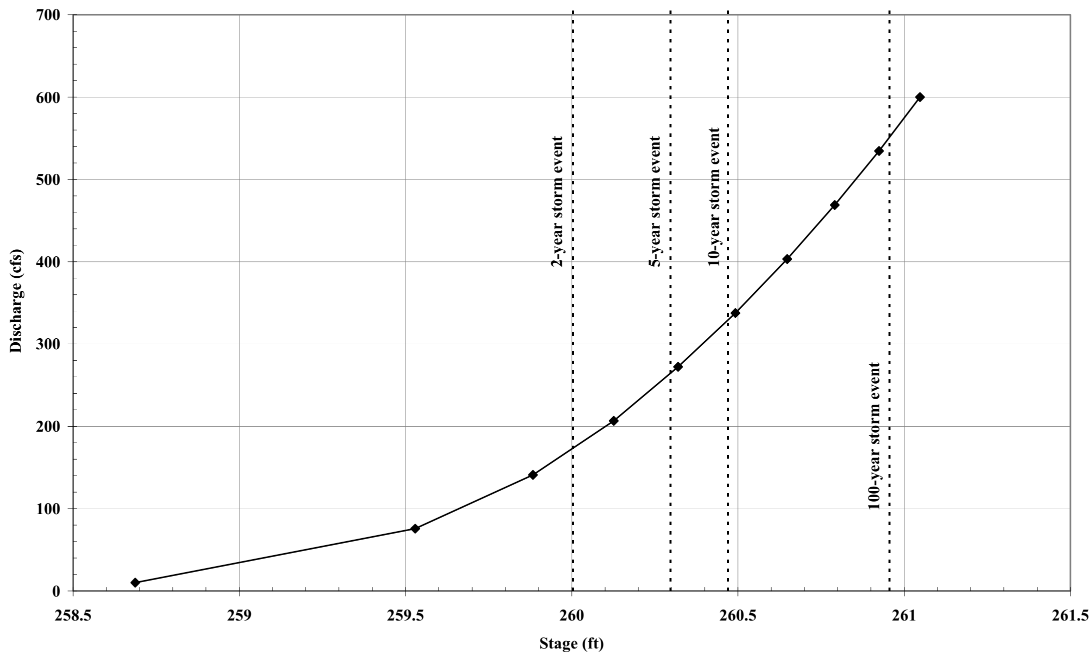


Figure A2. 36: Discharge versus stage relationship for geomorphic index point #7

Index Point #7

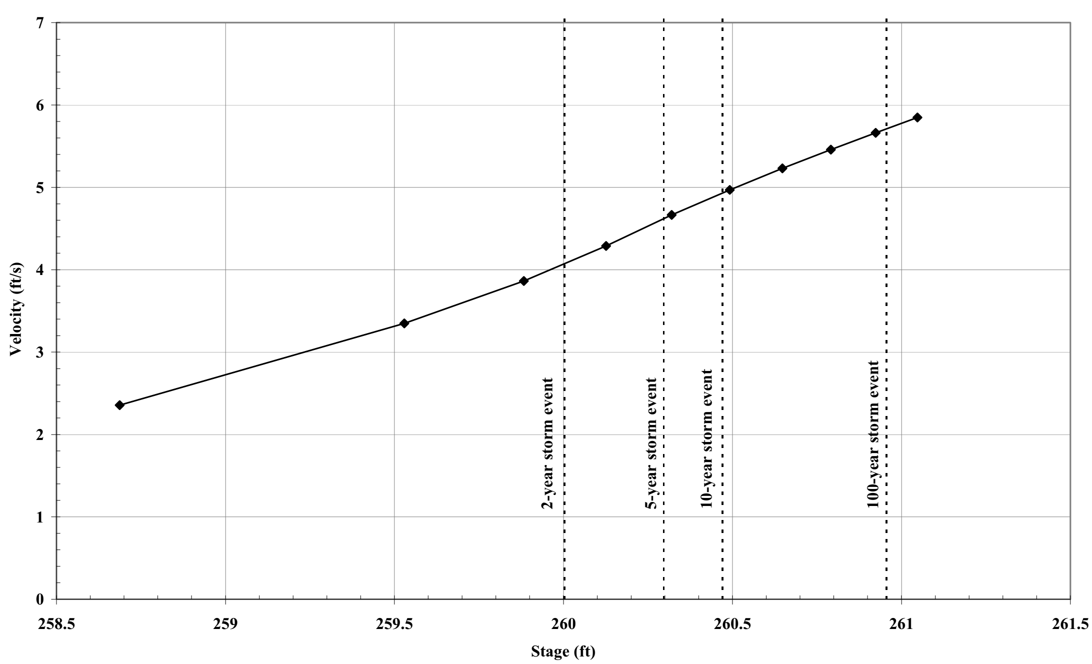


Figure A2. 37: Velocity versus stage relationship for geomorphic index point #7

Index Point #7

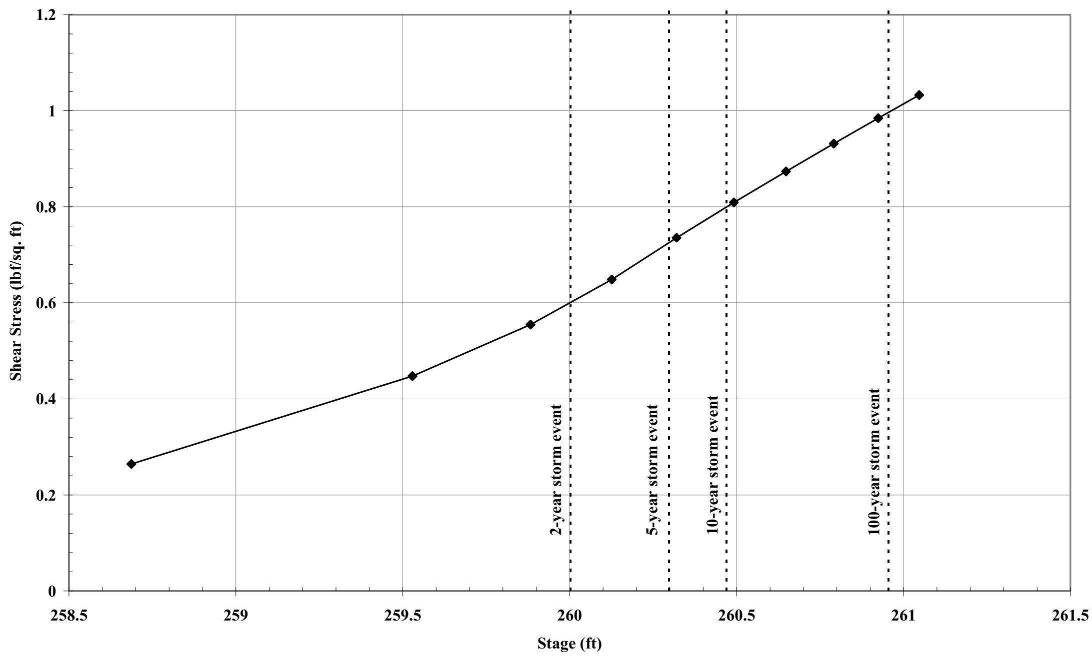


Figure A2. 38: Shear stress versus stage relationship for geomorphic index point #7

Index Point #9

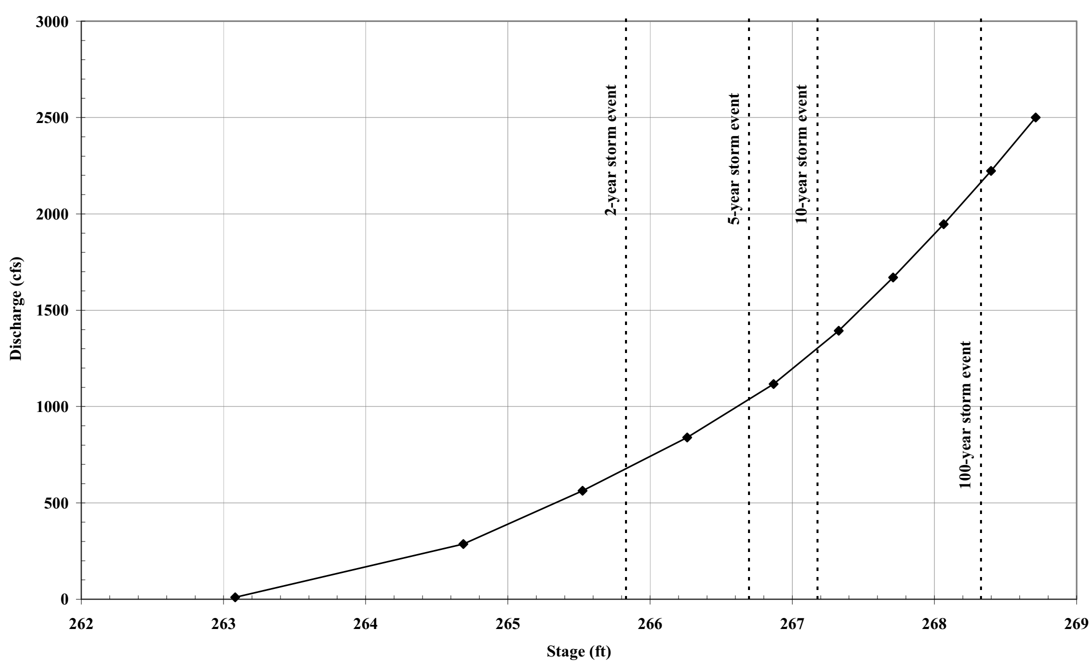


Figure A2. 39: Discharge versus stage relationship for geomorphic index point #9

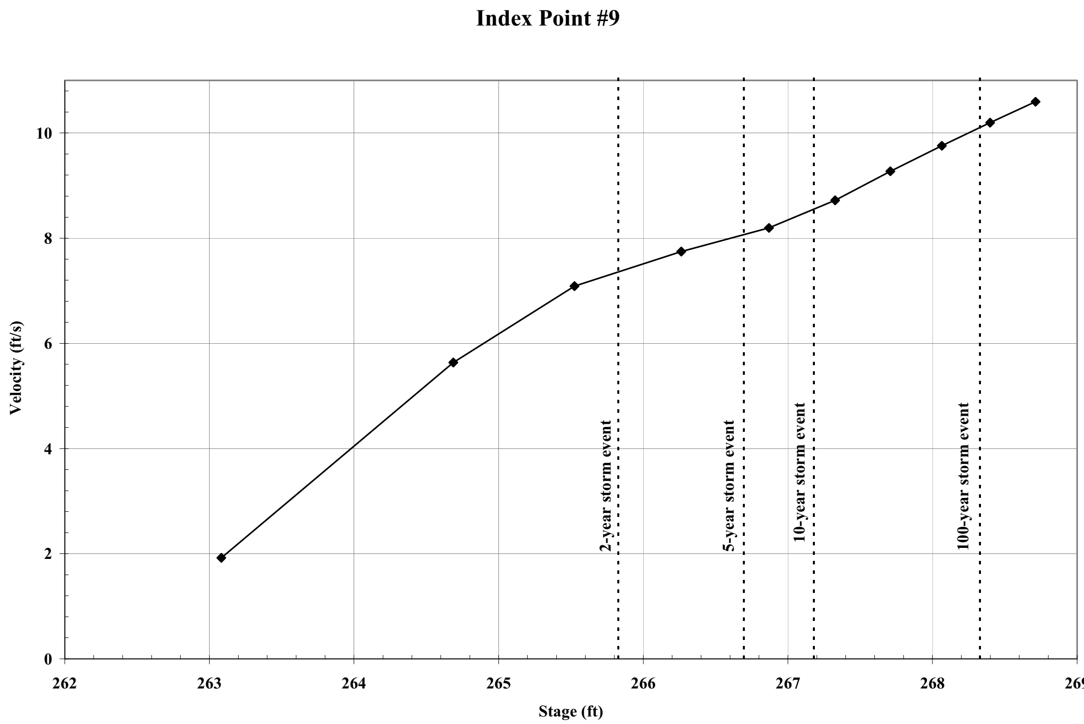


Figure A2. 40: Velocity versus stage relationship for geomorphic index point #9

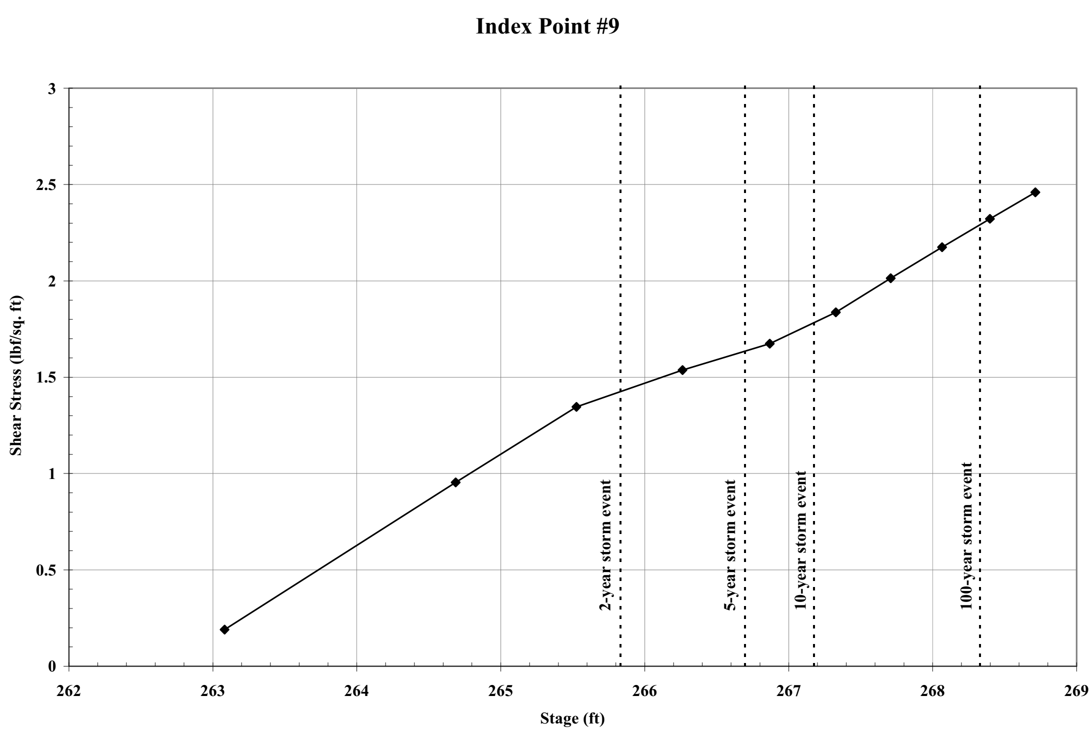


Figure A2. 41: Shear stress versus stage relationship for geomorphic index point #9

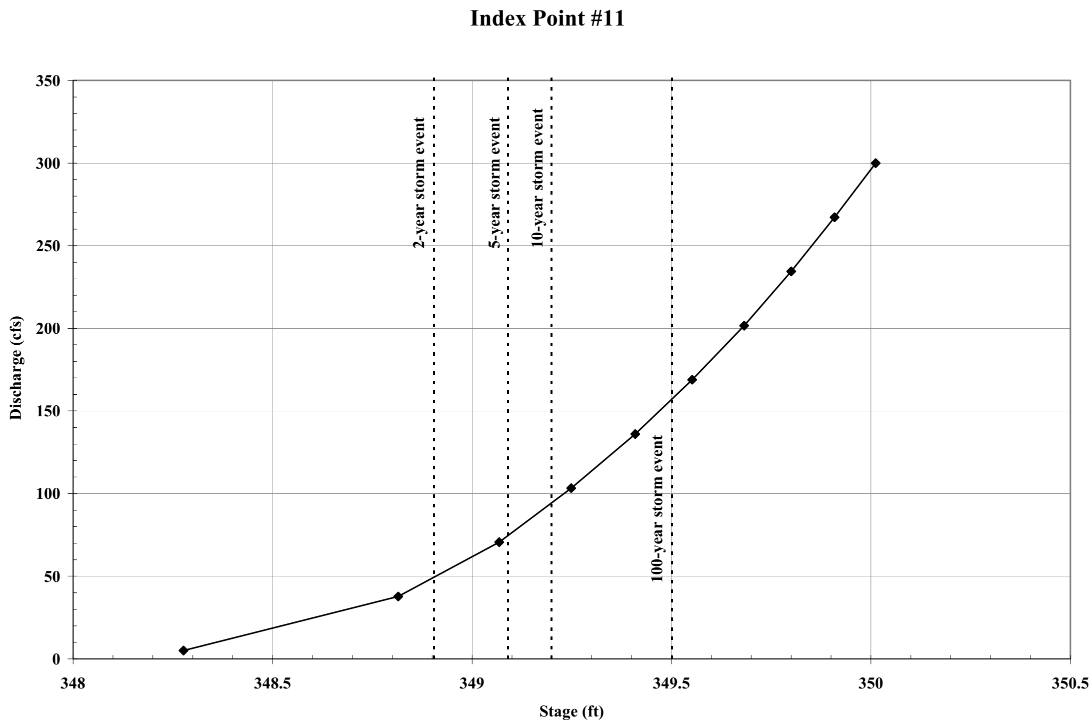


Figure A2. 42: Discharge versus stage relationship for geomorphic index point #11

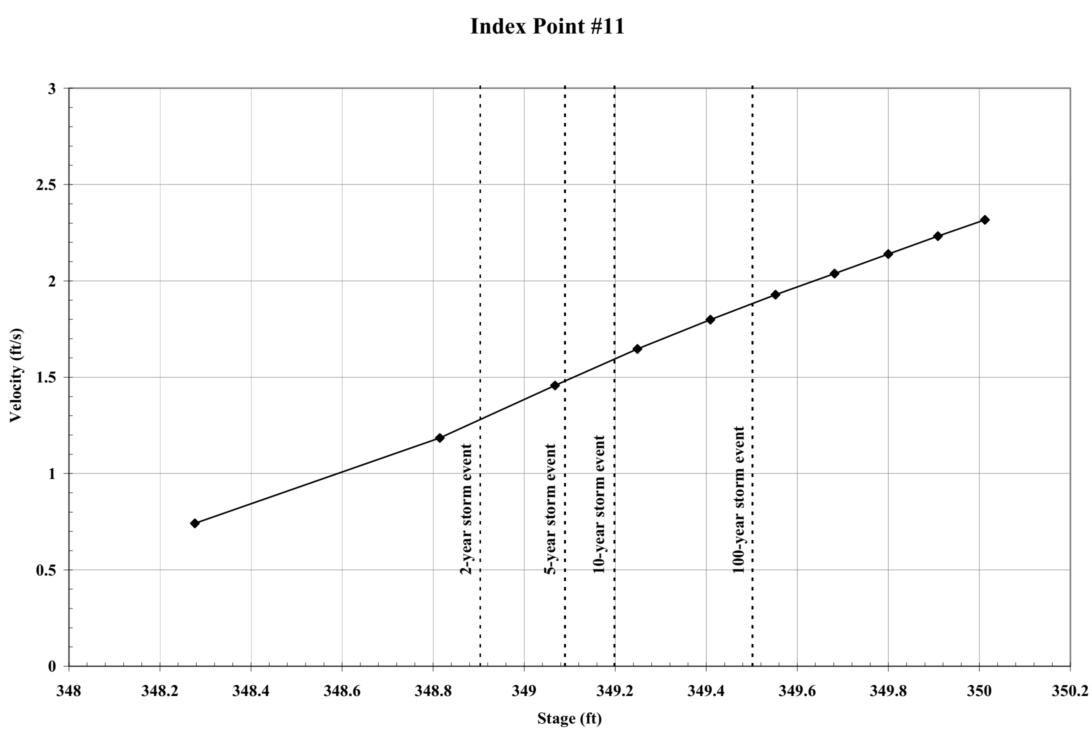


Figure A2. 43: Velocity versus stage relationship for geomorphic index point #11

Index Point #11

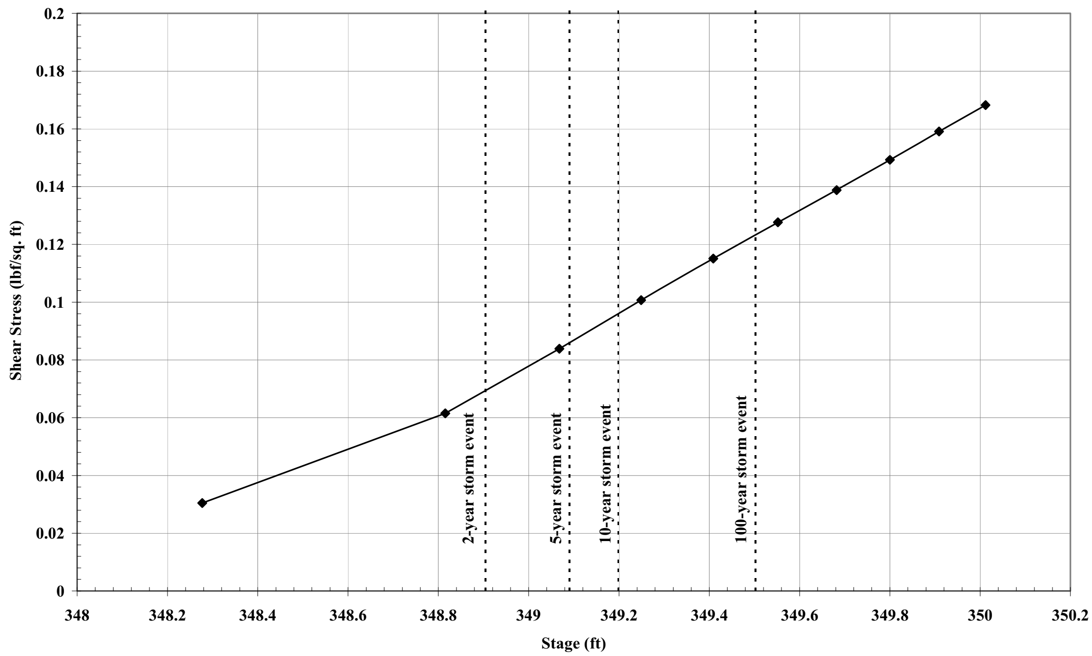


Figure A2. 44: Shear stress versus stage relationship for geomorphic index point #11

Index Point #14

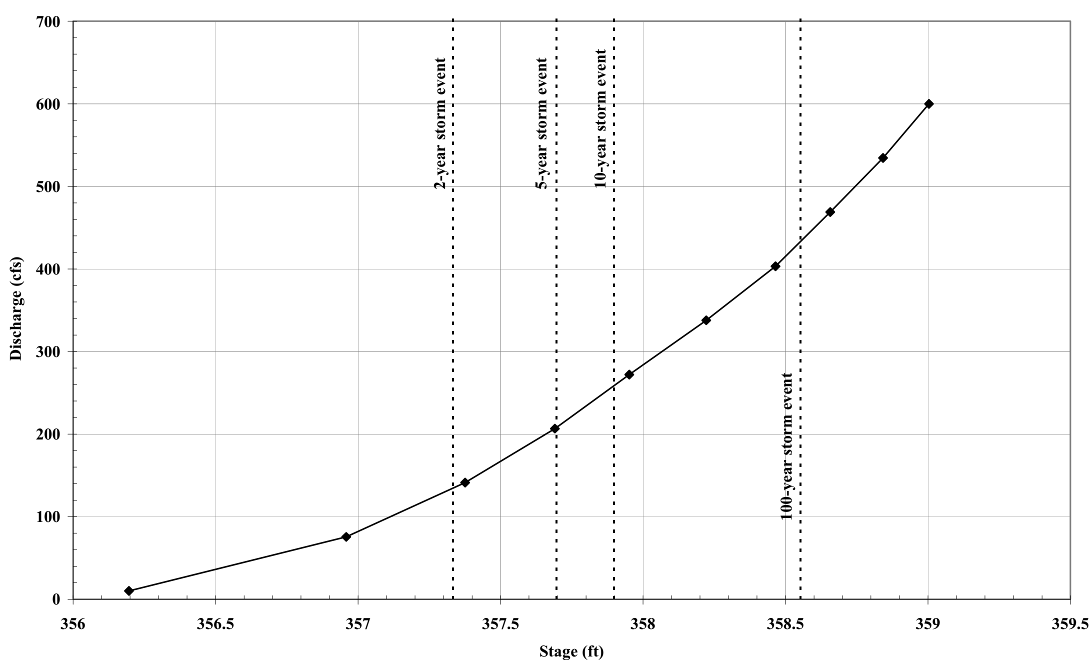


Figure A2. 45: Discharge versus stage relationship for geomorphic index point #14

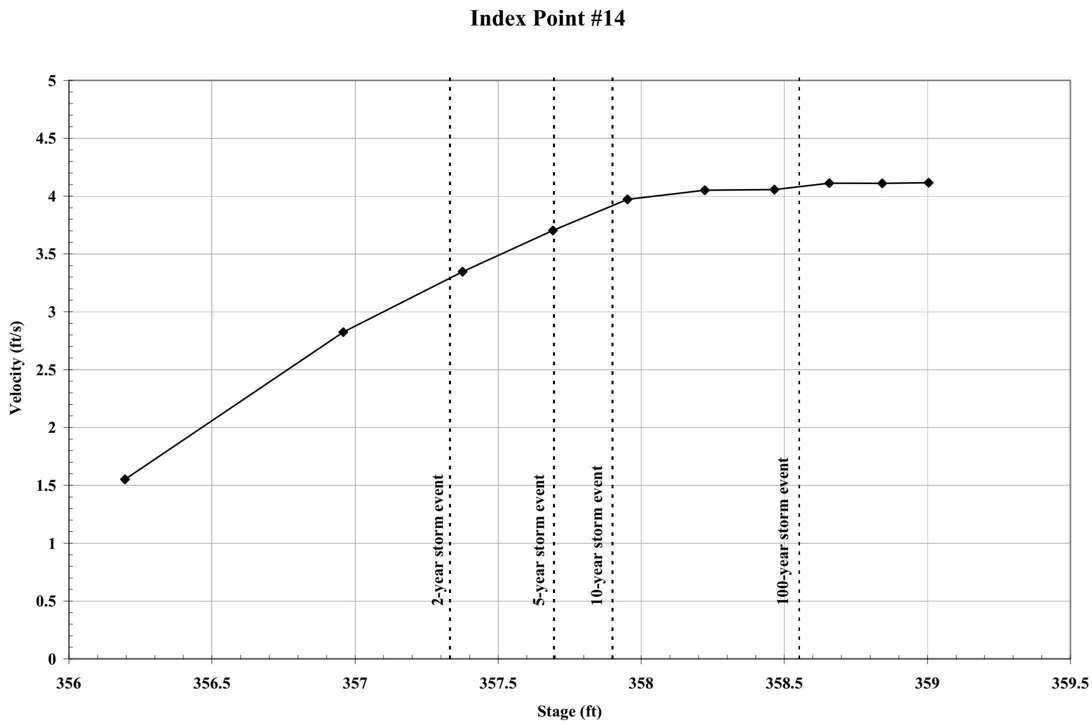


Figure A2. 46: Velocity versus stage relationship for geomorphic index point #14

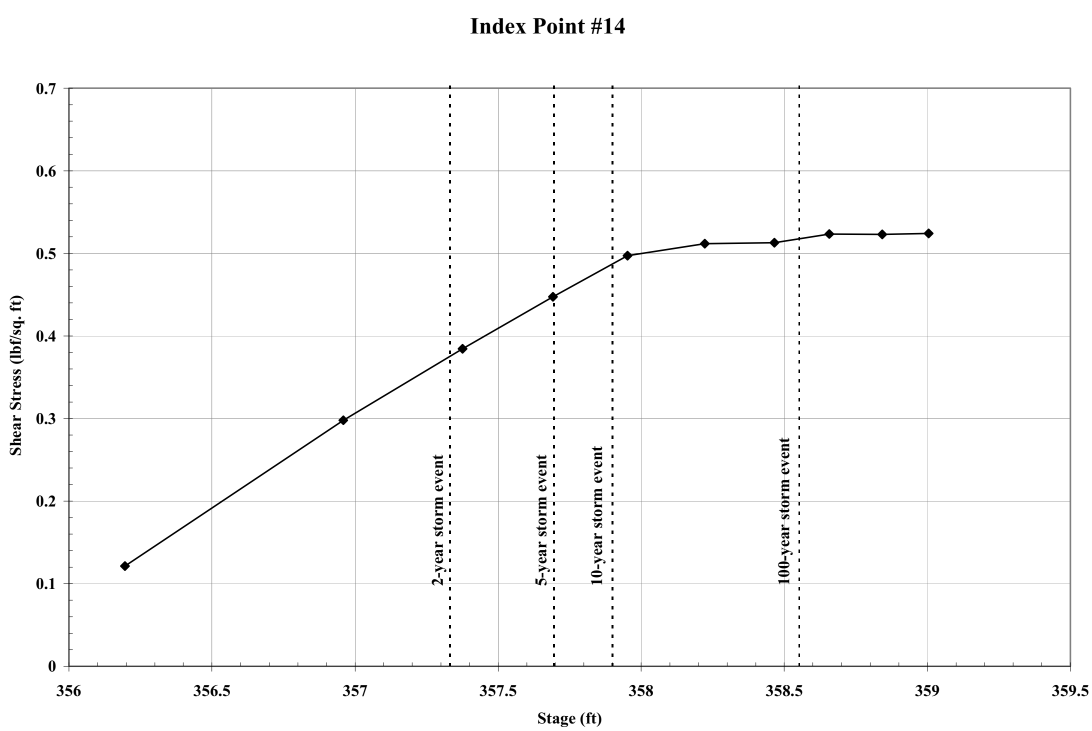


Figure A2. 47: Shear stress versus stage relationship for geomorphic index point #14

Appendix 2
Shear Index Distributions

<u>Notes:</u>

Shear index distributions are generated for geomorphic index points (sites 5, 6, 7, 9, 11, 14, ECORP-2, and Stagegage)

Hydraulics are generated using HydroCalc© (Molls, 2008)

The D_{50} at index points 5, 6, 7, 9, Stagegage and ECORP-2 are obtained form the bed material particle size distributions shown in Appendix 1.

No particle size data was available for Index points 11 and 14. The D_{50} at index points 11 and 14 are estimated to be the same as index point 9.

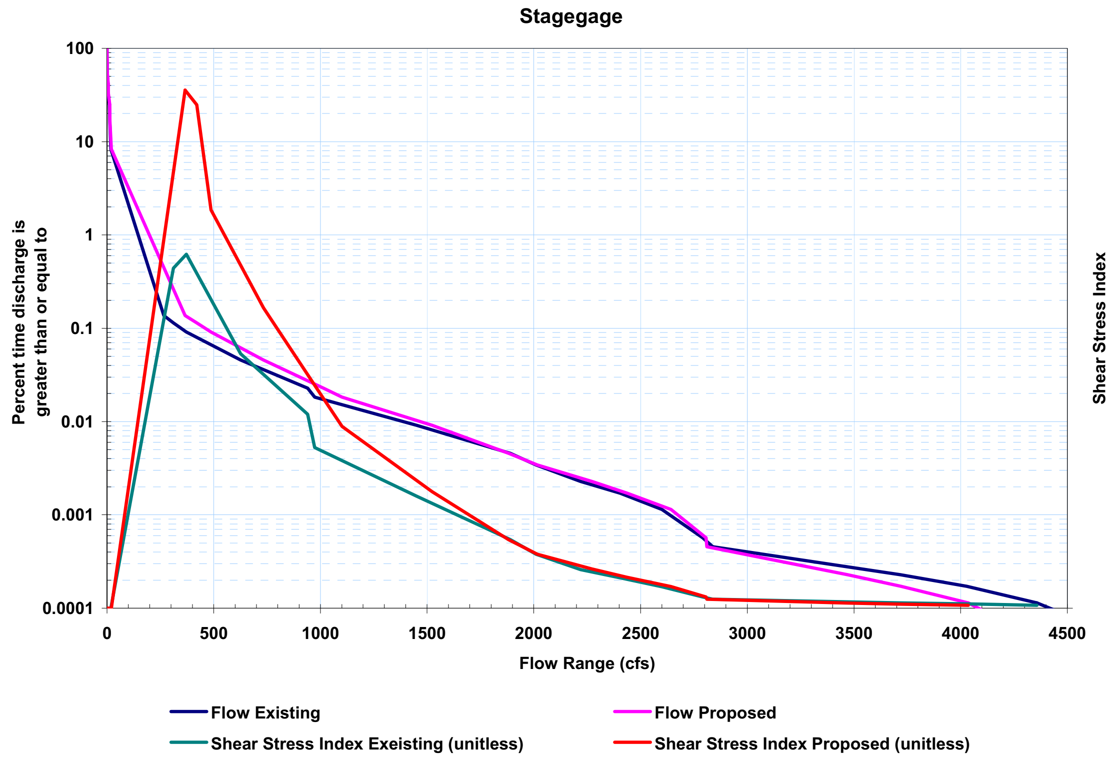


Figure A2. 48: Shear stress index for the Stagegage geomorphic index point

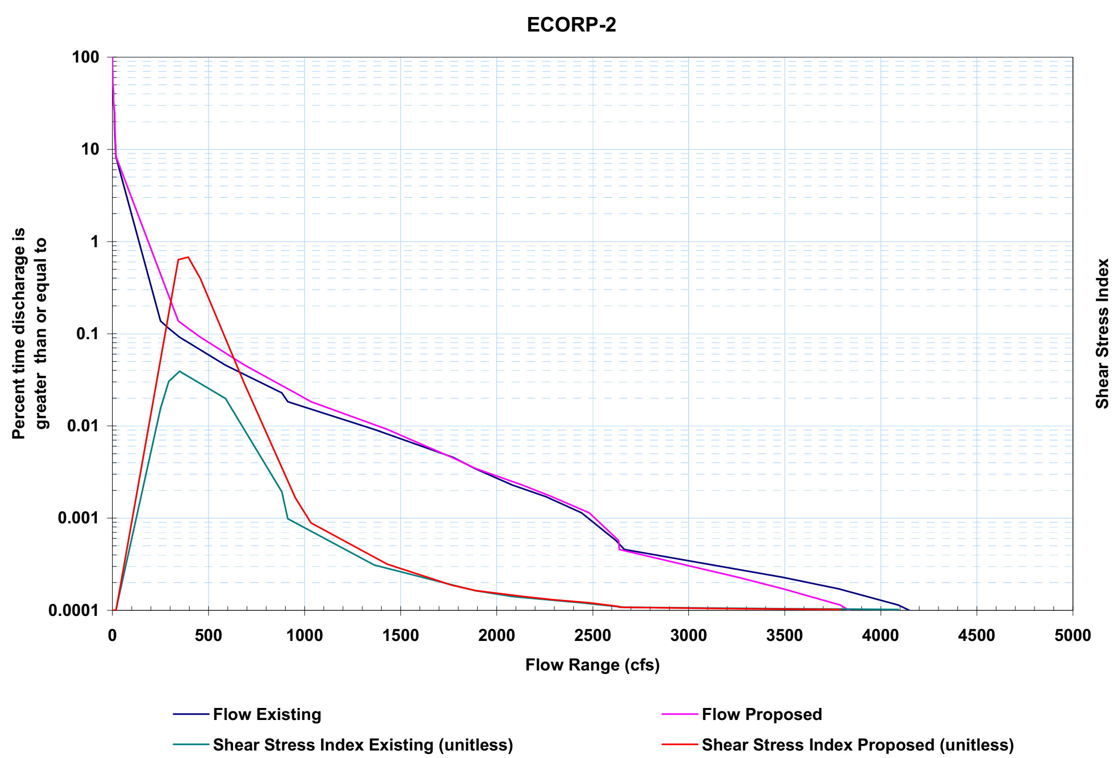


Figure A2. 49: Shear stress index for the ECORP-2 geomorphic index point

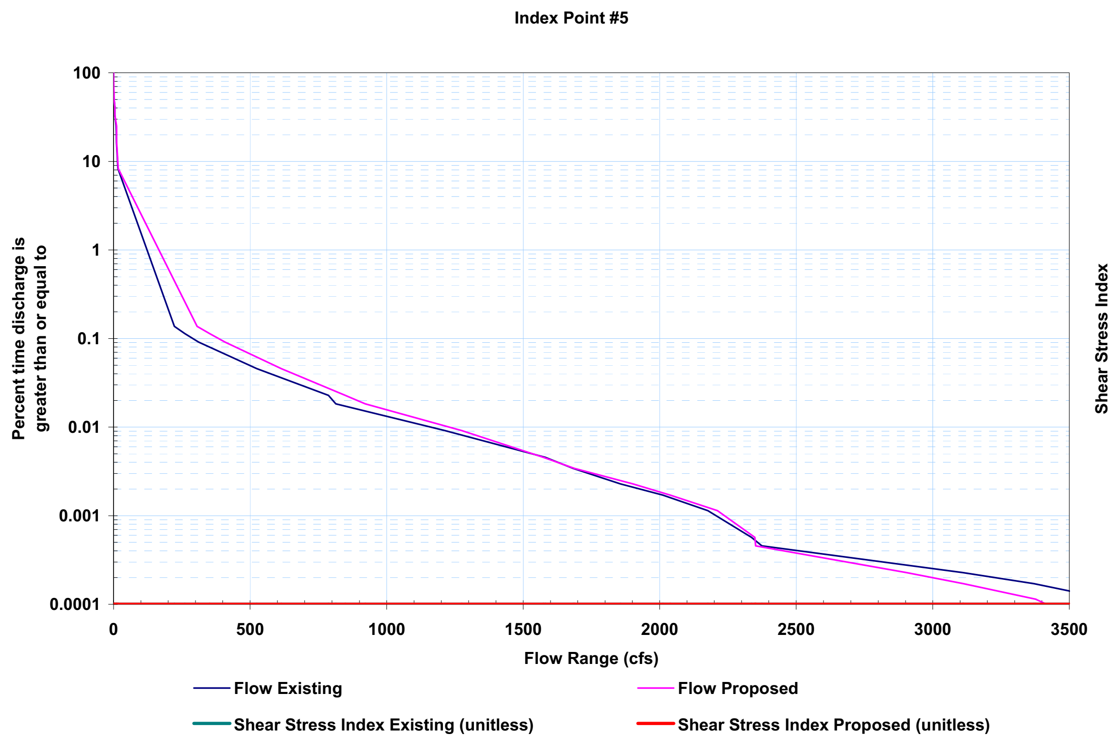


Figure A2. 50: Shear stress index for the geomorphic index point #5

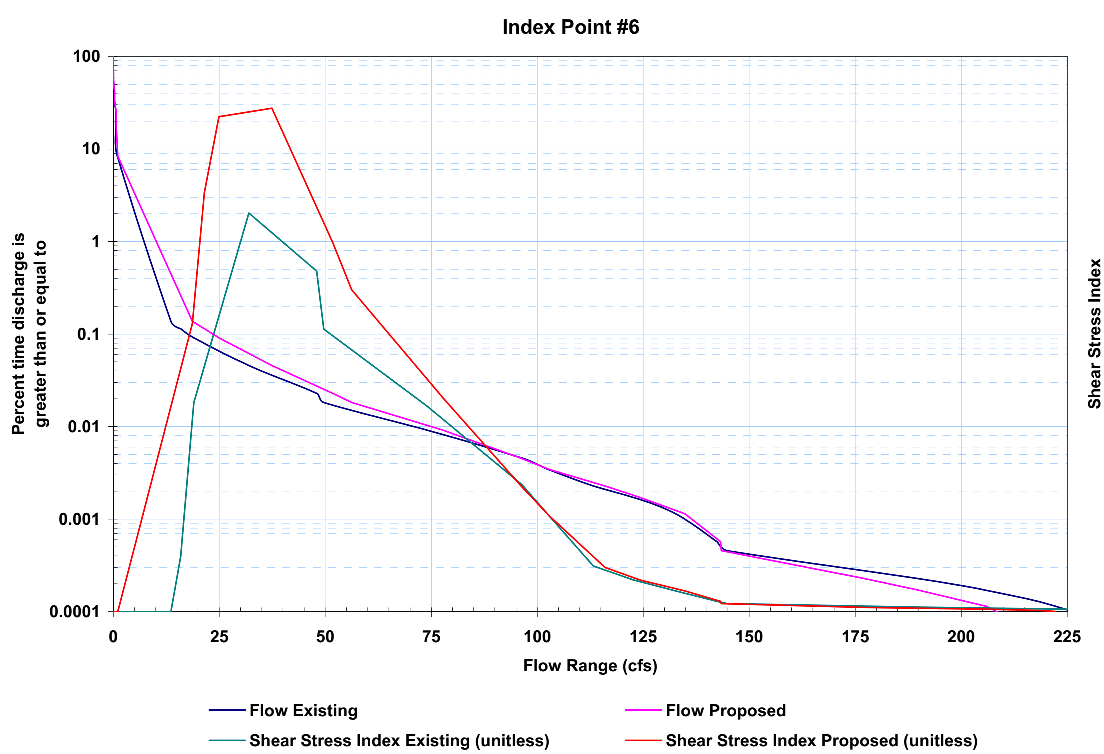


Figure A2. 51: Shear stress index for the geomorphic index point #6

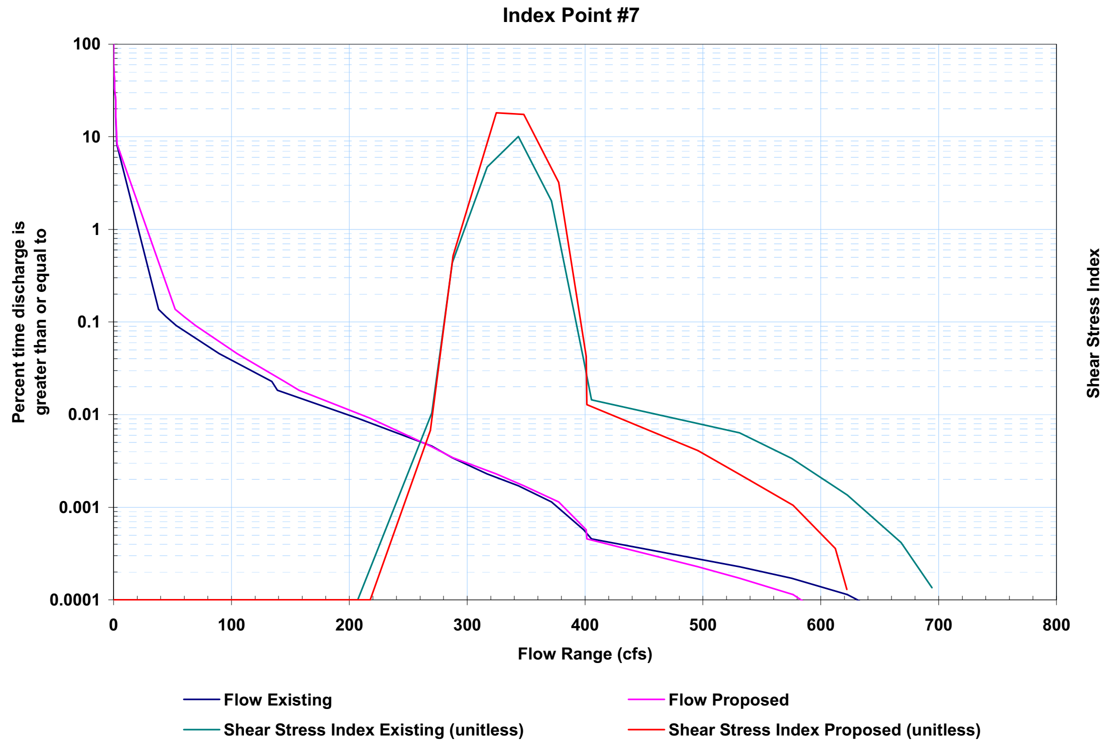


Figure A2. 52: Shear stress index for the geomorphic index point #7

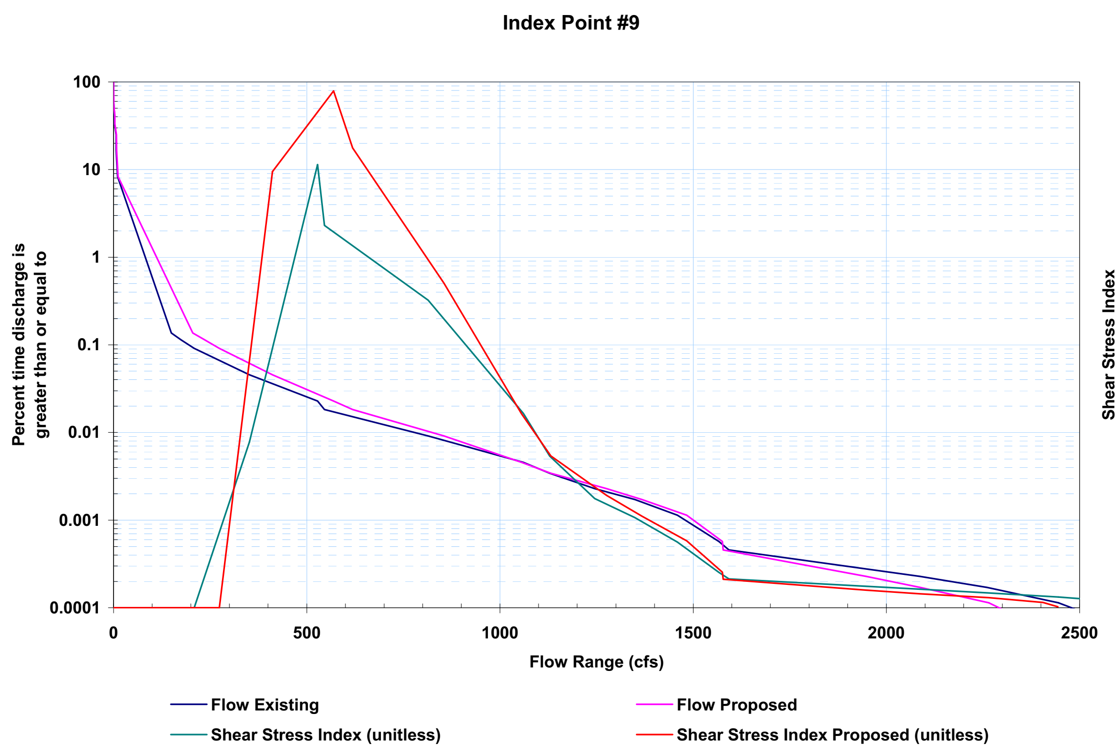


Figure A2. 53: Shear stress index for the geomorphic index point #9

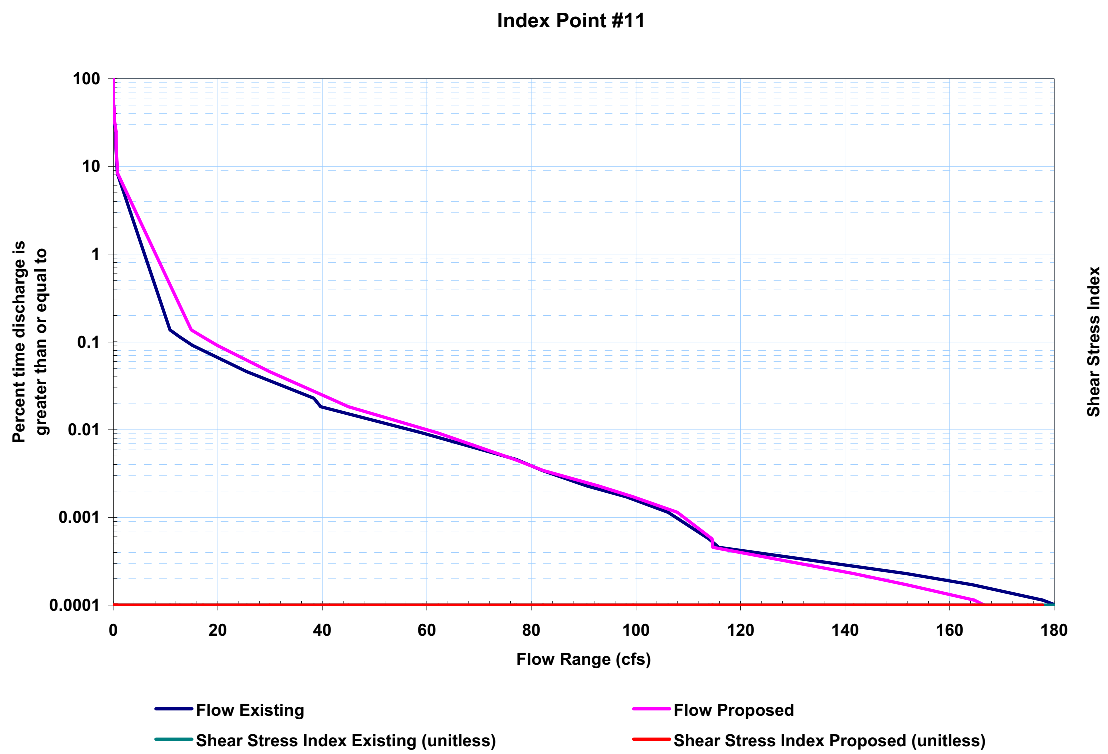


Figure A2. 54: Shear stress index for the geomorphic index point #11

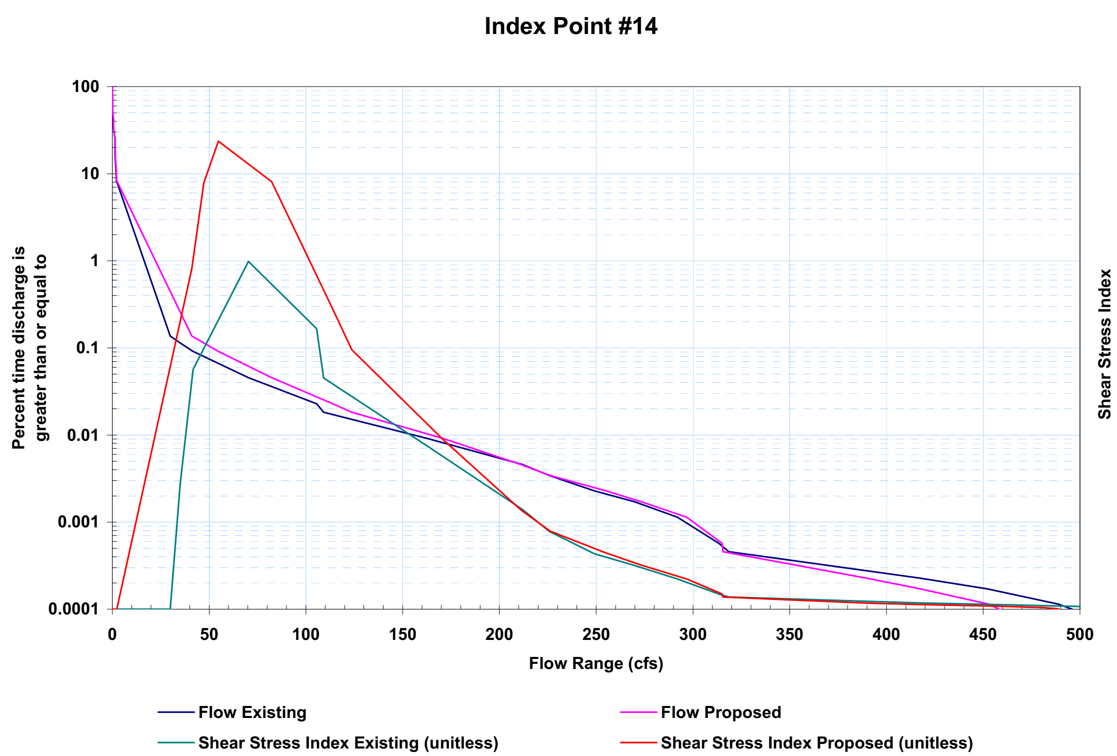


Figure A2. 55: Shear stress index for the geomorphic index point #14