FINAL DRAFT

Redesigning Marsh Creek Dam to allow Chinook salmon passage, flood protection, and mercury sedimentation

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Abstract

Marsh Creek has undergone several modifications for flood control purposes since the early 1960's. These projects included a grade-control drop structure and a flood-control dam, both of which impede fish passage along the creek. In addition, mercury pollution due to mine tailings at the upstream end of the creek has caused elevated mercury levels in stream biota and reservoir sediments. Although Chinook salmon have been observed in the lower reaches of Marsh Creek, the upper reaches are currently inaccessible, but would provide ideal salmon spawning habitat. Currently several proposals and plans exist to remove the drop structure and restore lower Marsh Creek, allowing salmon to migrate an additional seven miles upstream, as far upstream as the Marsh Creek Reservoir. In addition, the Contra Costa County Flood Control District hopes to redesign the reservoir to increase floodwater storage. This project presents a redesign of the Marsh Creek Reservoir, which allows fish access to the upper Marsh Creek spawning habitat, creates the flood storage capacity necessary to protect communities in the lower watershed, and attempts to minimize the impact of mercury pollution in the lower watershed. Given the increased public interest and support for restoration efforts along Marsh Creek, combined with the need for increased storage capacity of Marsh Creek Reservoir, a plan integrating fish passage, flood control, and mercury removal is essential.

Objective

Marsh Creek presents serious challenges to anadromous fish species: two physical barriers to fish passage and poor water quality due to upstream mine tailings. The lower of the two barriers is a five and a half foot grade-control drop structure, which has been targeted to be removed or modified to allow for improved Chinook salmon migration (NHI, 2003). The physical barrier addressed in this report is the Marsh Creek Dam, which will become a major passage barrier once the lower reach is opened. Elevated mercury levels have been reported in upper Marsh Creek and by connecting these reaches to the lower portion of the creek, mercury bioaccumulation may become a problem (Slotten, et al, 1998).

Since Marsh Creek Dam is needed for downstream flood control protection of several communities, removing the dam is not feasible at this time. Likewise, it is unlikely that any remediation of the Mt. Diablo Mercury Mine site will take place due to the associated liability of the tailings (Cain et al, unpublished). Therefore, there is a need for a design that provides sufficient flood control capacity and allows fish to migrate upstream, while also maximizing the mercury retention in the reservoir. All of these may be possible through an engineered design that separates the creek channel from the reservoir, except in high flow events when the creek recharges the reservoir otherwise functioning as a wetland. The basic goals and objectives of the design are:

- To allow Chinook salmon and other migratory fish species to reach the quality habitat of upper Marsh Creek;
- Create as natural a channel as possible, allowing two year recurrence floods and sediments to move downstream;
- To maintain the basic functions of the dam, including flood protection and maximum allowable discharge;
- To design the reservoir as a functioning wetland, with the goal of increasing mercury reduction through sedimentation and vegetative bioaccumulation.

While many flood control projects have been designed with fish passage as one of the defining variables, this paper is novel as it shows that flood control design is compatible with fish migration and passive heavy metal treatment.

Background

Marsh Creek begins on the east side of Mt. Diablo, flowing through protected oak woodlands, agricultural and grazing lands, and the towns of Brentwood and Oakley, until reaching the San Joaquin River delta at Big Break (Figure 1). The watershed is located in the rain shadow of Mt. Diablo, and thus receives only about 12 inches of rainfall per year (Western Regional Climate Center, 2003). Light rainfall and no snow pack result in the flows in the creek to be subject to rain events and, therefore the stream is frequently dry. The upper portion of the watershed consists of erodible sedimentary rock, shallow clay soils, and bedrock outcrops, while the lower watershed consists of deep alluvial soils deposited on the creek's floodplain (NHI, 2003).

Historically, Marsh Creek cascaded and then meandered east and north toward the delta and provided an important corridor for migrating wildlife, linking vital upstream habitat to the San Francisco Bay-Delta system. However, in the Marsh Creek watershed, agricultural and, more recently, residential development in the past several decades has been fast-paced. The population of Brentwood has increased approximately 120% in the last decade (City of Brentwood, 2003), so flood control has been a priority over habitat protection. Due to several intense floods in the 1950's, the Contra Costa County Flood Control District (CCCFCD) initiated several projects along Marsh Creek in order to prevent downstream flood damage (NHI, 2003).

To increase channel capacity, approximately ten miles of Marsh Creek were converted from a meandering, multi-channeled system with diverse riparian vegetation into a stable, singlestage trapezoidal channel devoid of vegetation (Figure 2). This reduction in the natural channel length had the potential to create a much steeper channel slope. To avoid the associated erosion with high-energy channels, the drop structure and a long concrete apron following downstream were installed (Figure 3). This structure is completely impassable to fish (NHI, 2003).

As another flood control measure, Marsh Creek Dam was built in 1963 and is located approximately seven miles upstream of the drop structure (Figures 4). The Dam is an earthen structure, owned and operated by the CCCFCD with a storage capacity of 4,425 acre-feet (DWR Bulletin 17-88). The dam was built solely for flood control and was designed for storage of a fifty-year storm event. The CCCFCD is currently working on a feasibility study to increase the dam capacity to provide storage for a 100-yr storm event (Mal Weston, CCCFCD, October, 2003). A large concrete culvert system links water in the reservoir with the stream below. The reservoir's main effect on the stream's hydrology is to dampen peak flows.

A third factor which impacts Marsh Creek is unrelated to flood control, but creates complications and hazards for both fish and humans. The Mount Diablo Mercury Mine, now inactive, is located along Dunn Creek, a tributary to Marsh Creek in the upper watershed. A report by Slotten, published in 1998, analyzed mercury loading in biota along Marsh Creek during a three-year period. This study shows that aquatic invertebrates and several fish species in Marsh Creek show substantially elevated mercury levels for the 10 to 12 mile stretch from the Dunn Creek confluence to just below the reservoir. Although the species size differed, similar loadings in parts per million were found in biota upstream and immediately downstream of the reservoir, suggesting that the water passing through the reservoir retains much of its high mercury levels. Much lower levels of mercury were found in animals sampled near the mouth of Marsh Creek. (Slotton, et al, 1998). It is hypothesized that during the high flow, high depositional events, the reservoir is short-circuited due to the proximity of the creek inlet to the dam outlet.

The rapid urbanization of the creek's lower reaches has drawn much attention from land use planners and restoration ecologists, hoping to integrate development plans with increased habitat, water quality, and stream function goals. The Natural Heritage Institute (NHI), for example, has developed restoration plans for lower Marsh Creek, including the removal of the drop structure, and for Dutch Slough, near where Marsh Creek reaches the Delta (NHI, 2003). Most of these plans are for the rapidly developing areas below Marsh Creek Dam, because the Dam's large infrastructure presents a major fish blockage and a sink for Mercury-laden sediments from the upper watershed. However, assuming the removal of the drop structure does eventually take place, the Dam will represent the next fish barrier along Marsh Creek.

Methods

Our design process for the Dam alterations included several steps of data collection, analysis, and calculations. NHI was able to provide historical photographs, and current restoration proposals and plans. CCCFCD also provided valuable information regarding the design parameters for the existing dam, as well as historical, and future design parameters. We interviewed an environmental scientist and hydraulic engineer from DWR's Fish Passage Improvement Program regarding migration and spawning requirements for Chinook salmon. We were able to find journal articles regarding wetlands for mercury treatment, as well as wetlands for flood control. Length, slope, and area calculations were done using Arcview3.x, United States Geologic Survey (USGS) maps, and the USGS 7.5 meter National Elevation Data.

We obtained daily flow and annual peak flow data from the USGS website for Marsh Creek gauge# 11337500, which was operated upstream of Marsh Creek Dam from April 1953 to

September 1983. USGS gauge# 11337600 was installed downstream of the reservoir in the town of Brentwood in August 2000 (USGS, 2003). CCCFCD provided maximum reservoir water surface elevations for years 1972 through 1997 and a relationship between water surface elevations and reservoir discharges.

From the years with both reservoir maximum water surface elevation data and Marsh Creek peak flow data (1973 through 1983), we developed a regression to match peak flow events with reservoir water levels (R^2 = 0.95). With this, we calculated hypothetical peak flow events for Marsh Creek above the reservoir for 1984 through 1998. This allowed the maximum peak flow data to span over 45 years as opposed to only 30 years. We used this data to develop a flood frequency curve for Marsh Creek, shown as Figure 5 in the appendix.

In order to properly size a new design culvert, we examined the water surface elevation corresponding to reservoir discharge data from CCCFCD in conjunction with National Marine Fisheries Service's (NMFS) "Guidelines for Salmonid Passage at Stream Crossings (2001)". The maximum allowable release from the reservoir was the discharge corresponding to the maximum reservoir water surface elevation prior to water reaching the emergency spillway. NMFS (2001) recommends designing a culvert for 50% of the 2-year flood recurrence (190 cfs for upper Marsh Creek) for high flow situations and 3 cfs for low flow situations for adult fish. Water velocities in a culvert between 200 and 300 feet in length should be less than three feet per second and water depth should be no less than 12 inches for adult salmonids during low flow events. The culvert should be no less than three feet wide, not greater than 0.5% slope, and be embedded into the streambed to a depth of about 20% of the culvert height. In addition, water surface elevations should exhibit gradual transitions in both the upstream and downstream ends of the culvert (NMFS, 2001). We used both the software Flowmaster and the Bureau of Public

Lands culvert sizing charts to create the final culvert design and to calculate cross sectional averaged velocities.

We gauged the quality of the spawning habitat from field observations, discussions with professionals, and a substrate analysis provided by NHI. Current reservoir conditions were based on visual observations by the authors, as well as the "Marsh Creek Watershed, second edition (NHI, 2003)". Mercury concentrations in stream biota and sediments were taken from Slotton's 1998 "Marsh Creek Watershed Mercury Assessment Project".

Using this data, the results from research, knowledge of flood control, and the hydraulic requirements for Chinook salmon migration, we created a updated design for Marsh Creek Reservoir that takes advantage of the current layout, and meets all of the objectives outlined above. This design plan not only allows salmon passage, and retains the necessary flood control capacity, but also creates a wetland that will maximize the mercury settlement within the wetland, and so minimize the impact of mercury on downstream organisms and vegetation.

Results and Discussion

Design Overview and Goals

The conceptual design uses the existing reservoir for flood storage, but would only allow overland flow into the reservoir during high flow events. An earthen, boulder, and concrete berm will separate this channel with the existing reservoir, which will function as a constructed wetland and will be sized to provide the necessary storage capacity. The berm will isolate the stream from the reservoir in low flow events, but will be set at 7.0 feet, the water surface elevation corresponding to a flow of 390 cfs and the bypass channel configuration (Figure 6). The upstream edge of the berm separating the wetland/ reservoir from the active channel will end in a concrete flow diversion structure, which is sized to allow the passage of flows above the 2-

year storm event, and will withstand the water forces of high flow events (Figure 7). Through this design, a natural, albeit scaled down channel will exist alongside the reservoir the majority of the time, with the reservoir/wetland providing not only flood storage, but also an area of high residence time for mercury-laden sediments to settle out of the water column. The current dam passage structure will be replaced with a new inlet/outlet structure and a new culvert, which is sized to meet the maximum allowable discharge and to allow for fish passage. Details of this design can be seen in Figures 6 through 8.

Hydrology/ Hydraulics

A watershed of approximately 33,000 acres drains to Marsh Creek Dam, which provides flood protection to the downstream watershed by storing water during high flow events, and slowly releasing it downstream after the peak of the storm runoff has passed (NHI 2003). Due to the local topography, Marsh Creek flows into the reservoir along its west side, and at low flow flows directly to the reservoir outlet also located along the west side of the river (Figure 9). Despite this, because of the large amount of surface area available in the reservoir, much of the energy of the stream is absorbed as it passes through this reach, and water velocities slow down greatly. During the late summer and fall, upper Marsh Creek is dry and the reservoir is below the elevation of its outlet and thus not releasing any water.

The 2-year flood recurrence is 390 cfs according to the upstream gauge data as calculated using the flood frequency curve. This flow was used to size the active flow channel, as it often represents a critical channel-forming flow. All flows below 390 cfs will remain in this bypass channel and not mix with water that may be present in the reservoir. When the in-channel flow exceeds 390 cfs, the water surface elevation will reach the height of the diversion structure and excess water will begin to spill into the reservoir/wetland.

An analysis of the velocities show that as the flow immediately widens upon entry to the wetland, the velocities will drop dramatically. This is important to ensure fish know which way to travel if they are migrating during a period when the flow is higher than a 2-year event (C. Lee, DWR, personal contact, 2002).

Culvert Through Marsh Creek Dam

At elevation 168 NGVD, the reservoir outlet receives no flow and at 191.8 NVGD, the water surface reaches an emergency spillway on the top of the Dam (CCCFCD). The average water surface elevation of 172.9 NVGD and the maximum value of 191.8 NVGD corresponded to reservoir discharges of 446 and 598 cfs, respectively. Therefore, we selected 598 cfs as the maximum allowable release from the dam. The high and low flow extremes for design of proper fish passage according to NMFS, as described in "Methodology" are 195 cfs and three cfs, respectively. We attempted to size a culvert that meets both of these flow parameters: allowing fish passage while limiting downstream flow.

In addition, the culvert must take into account the head created above the culvert inlet during high flow events. When the water surface elevation reaches the emergency spillway, the head applied to the current culvert is approximately 24 feet (192-168). For convenience, we used this same relationship for culvert sizing. This does not necessarily mean that the culvert will experience pressure flow at all flows greater than the 2-yr event, rather that when the reservoir is full, the culvert receives a total of 24' water pressure. Using Bureau of Public Roads Chart 6 and methodology described above; this yielded a maximum circular culvert diameter of 84" (Figure 10, rounded down to account for additional actual head). However, when designing for fish passage, due to the lack of head driving the flow, a larger culvert is needed. In other words, the culvert needs to be smaller for flood control than for fish passage. The summary of this data can be found in Table 1. One solution to this dilemma would to design a box culvert based on the fish passage criteria, and to partially lower a gate during high flow situations to limit the downstream flow. This process could easily be made automatic, and would not disrupt the fish passage capacity of the culvert. Additional analysis and culvert modeling is necessary to establish the actual maximum release flows and culvert sizing options.

Habitat

For the stretch of Marsh Creek beginning about three miles downstream of the reservoir and running to the creek's mouth at the Delta, the channel becomes almost purely trapezoidal with little or no riparian vegetation. This lower stretch contains mostly silt and boulders from implanted riffles (Figure 11) and serves mostly as a thoroughfare for migrating salmon as the bed material is not suitable for the formation of redds. Although salmon migration has been stopped below the drop structure on the creek, salmon have been seen attempting to spawn (NHI, 2003).

In general, Marsh Creek has maintained a healthy riparian corridor and channel form upstream of the Dam, as well as for approximately three miles downstream of the Dam. Above the Dam, the shade from the riparian trees and the abundance of gravels and cobbles provide ideal spawning habitat for Chinook salmon that is currently inaccessible (C. Lee, DWR, personal contact, 2002). Low-density grazing and open space preserves have protected the physical integrity of these reaches in the upper watershed. Once accessible, these upper reaches have the potential to sustain a healthy Chinook salmon population.

Field observations showed that for approximately three miles downstream of the Marsh Creek Dam and for about 10 miles upstream of the Dam, the habitat is similar in quality: an exposed, un-armored gravel bed with a thin, but healthy riparian fringe. The substrate analysis, performed one mile downstream of the Dam, showed that the dominant mode of sediment was in the gravel range (2-16 mm), with a fairly low standard deviation that indicates (and supports field notes) a well-mixed particle distribution (NHI, 2003). This value is approximately in the required range of salmon spawning gravels (Kondolf, 2003). An environmental scientist from DWR's Fish Passage Improvement Program visually examined the gravel bed and confirmed that this would be quite suitable for salmon redds (C. Lee, DWR, personal contact, 2002).

This design plan for the reservoir diversion channel does not stress the importance of habitat in the local reach, as the project is focused on getting the salmon through the culvert and around the reservoir. While riparian vegetation will be planted, its primary purpose will be bank and berm stabilization rather than stream shade and channel form diversification.

Sediment Transport

The low flow channel for the design is scaled for a 2-year flow, as it is often reported that this flow is responsible for the majority a river's total sediment transport (NHI, 2003). The sediment that is important to salmon spawning comes in the form of bed load and involves cobbles and gravel rolling and bumping along the channel bottom (Julien, 1998). During high flood events when these particles are mobilized, they will still remain within the confinement of the banks of the main flow channel. Therefore, even though high flows will result in water surface elevations higher than the separation berm, large sediments will still move down the line of the main channel and through the embedded culvert to the lower part of Marsh Creek. We believe this will minimize sediment build up within the low flow channel.

Fine sediments, however, will be suspended as wash load and will be both present above the main channel bottom and in the flow received by the reservoir (Julien, 1998). When the flow velocities slow down in the reservoir, some of the suspended material will settle out (Ciszewski, 1998). It has been shown that in channelized streams surrounded by wetland, wash load particles (defined as less than 0.1 mm) accounted for 95% of the total sediments delivered to the wetland (Nakamura, 1997). These findings have important implications for the mercury present currently present on the stream's fine particles.

Mercury Removal

Currently, during the dry season, the Marsh Creek Reservoir formed by the dam has a thick wetland fringe, and supports diverse vegetation and animals. Although wetlands can retain up to 90% of mercury in its sediment (Mulamoottil, et al, 1998), in Marsh Creek, similar concentrations of mercury were found both upstream and immediately downstream of the reservoir (Slotten, et al, 1998). We believe this is caused by the proximity of the creek inlet to the dam outlet which creates a flow situation such that except in very large depositional events, the retention time needed in the wetland to achieve a high removal rate is not met. Therefore, little mercury retention occurs as the flow passes through the reservoir. As confirmed by Slotten et al, the downstream mercury levels do not differ significantly from the upstream concentrations. Surficial sediment mercury concentrations in Marsh Creek Reservoir ranged from 0.27 to 0.57 ppm for a three-year period of 1995 though 1997, with the largest mercury depositional periods associated with the largest flow events (Slotten, et al, 1998). Mercury levels in fish are on the order of 0.20 ppm both in and downstream of the reservoir (Slotten, et al, 1998).

Constructed wetlands have been shown to be effective at removal trace metals, including mercury, through sedimentation and bioaccumulation in wetland plants (King, et al, 2002 and Terry, el al, 1999). Often the residence times are too short to be effective in metal removal, as illustrated by the lack of mercury removal from the wetland of Marsh Creek reservoir. Ideal residence times are on the order of five to 14 days using a first-order removal model (Goulet, et al, 2001).

With the proposed design most sediments will be transported downstream of the Dam in the main stream channel. This would result in little or no increase in sediment retention over current conditions, and, during low flow events, will not affect the mercury loading downstream. However, as discussed earlier, high flows are responsible for the majority of wash load transport and mercury deposition in the reservoir and these flows are the exact conditions when the wetland will receive sediments (Slotton, et al, 1998 and Ciszewski, 1998). Therefore, by restricting the connectivity of the reservoir with the main channel, the new design plans that with high flow, high transport events, hydraulic residence times will be increased leading to increased mercury removal rates. Additionally, plants that have been shown to be effective in the uptake of mercury, such as saltmarsh bulrush and rabbitfoot grass, will increase the mercury treatment within the wetland (Terry, et al, 1999). As this water slowly seeps through the berm back to the main channel, we believe it will contain much less mercury-laden sediments than prior to entering the wetland and thus increase downstream water quality. Although this design certainly does not solve the problem of mercury loading in Marsh Creek, it attempts to capitalize on what in-situ treatment may be possible, and at the very least, not negatively impact downstream mercury contamination.

Conclusion

This report proposes an alternative to the current Marsh Creek Dam structure at a time when plans to modify the reservoir to increase flood capacity are beginning to be considered. The reservoir improvement project presents a unique opportunity to combine flood control with habitat restoration and fish passage priorities. As outlined above, our proposal allows for fish passage while maintaining storage capacity and utilizing a constructed wetland for mercury sedimentation. This represents a novel approach to a accomplishing the three objectives of fish passage, flood control, and water treatment. Although the proposed design does not totally remove the mercury loading to Marsh Creek, it does maximize what treatment is possible within the reservoir. In the long run, the only way to truly deal with the mercury contamination will be to treat the source, however small steps to minimize the impact on the Creek can make a difference.

Additional analysis is necessary to create the final dimensions of the reservoir not only to create the exact storage capacity required, but also to compensate for any sediment loading to the reservoir, though with the design described herein, much of the watershed sediment will simply be naturally transported downstream. With careful planning and caring participants, it certainly may be possible for all of Marsh Creek to be an accessible and healthy spawning ground for Chinook salmon.

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Table One: Table of culvert design results

Figure One: Marsh Creek Location Map

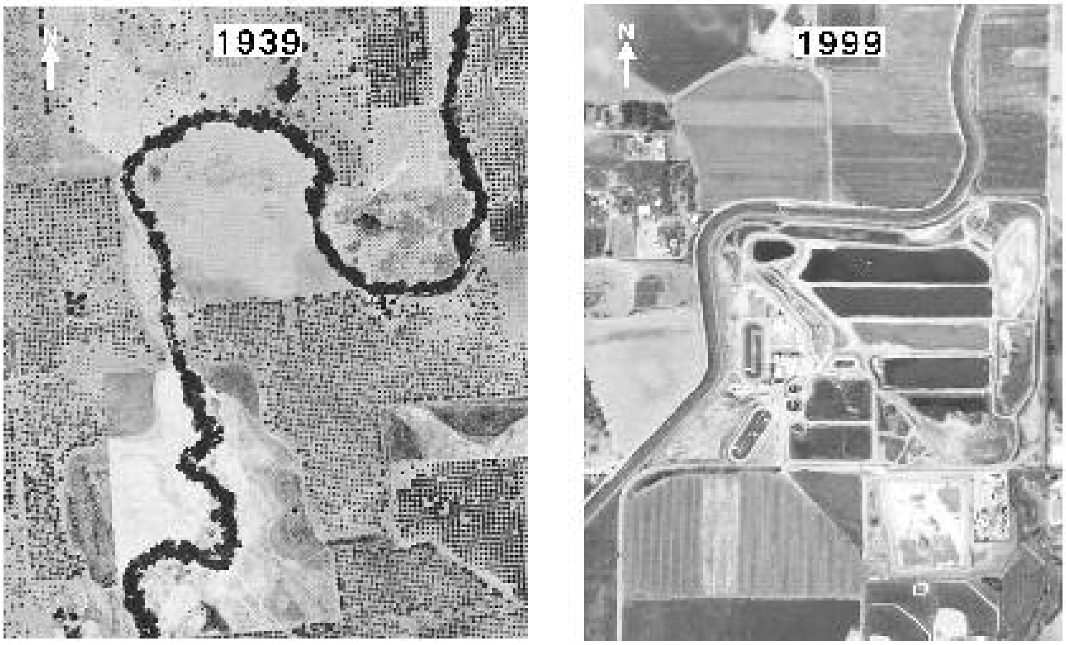

Figure Two: Example of restructuring and channelization of Marsh Creek for flood control. Note lack of channel form diversity and loss of channel length.

Figure Three: Drop Structure on Marsh Creek, looking Upstream

Figure Four: Downstream Face of Marsh Creek Reservoir dam

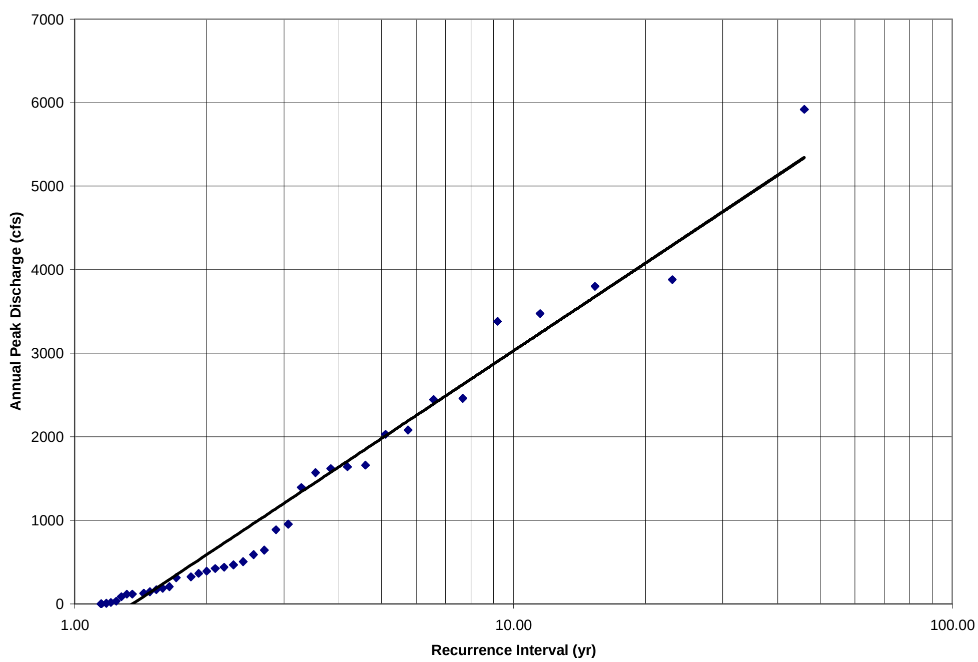

Figure Five: Flood frequency curve for Marsh Creek above reservoir

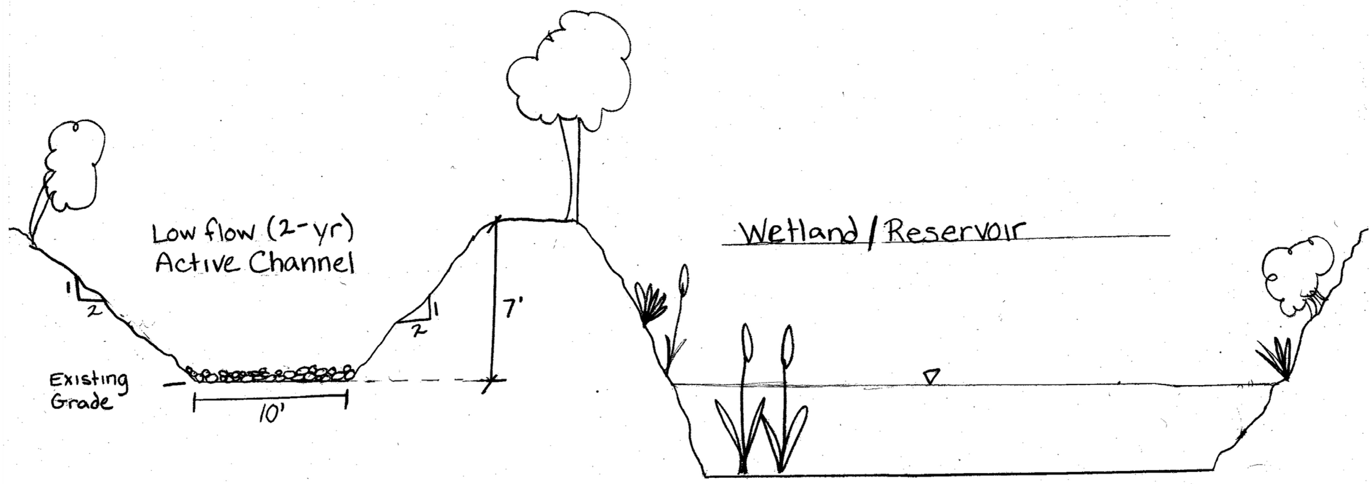

Figure Six: Typical cross section of diversion channel and reservoir

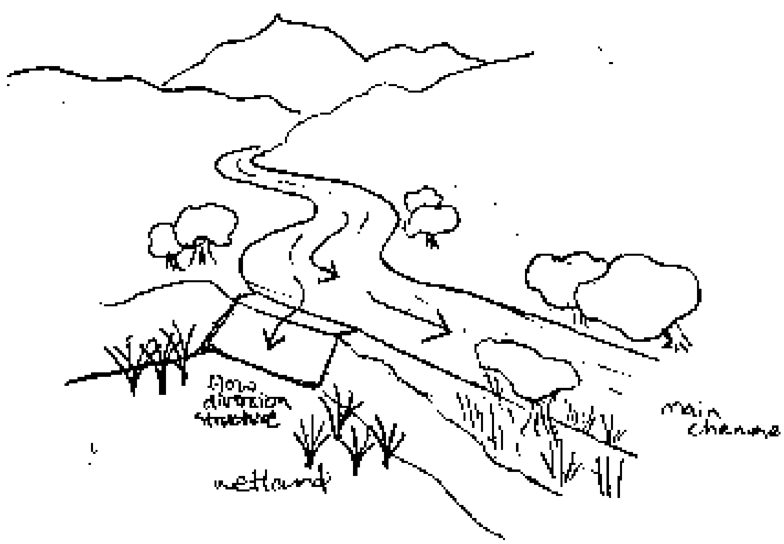

Figure Seven: Looking upstream at the beginning of the wetland/reservoir connected to the separated channel by a flow diversion structure.

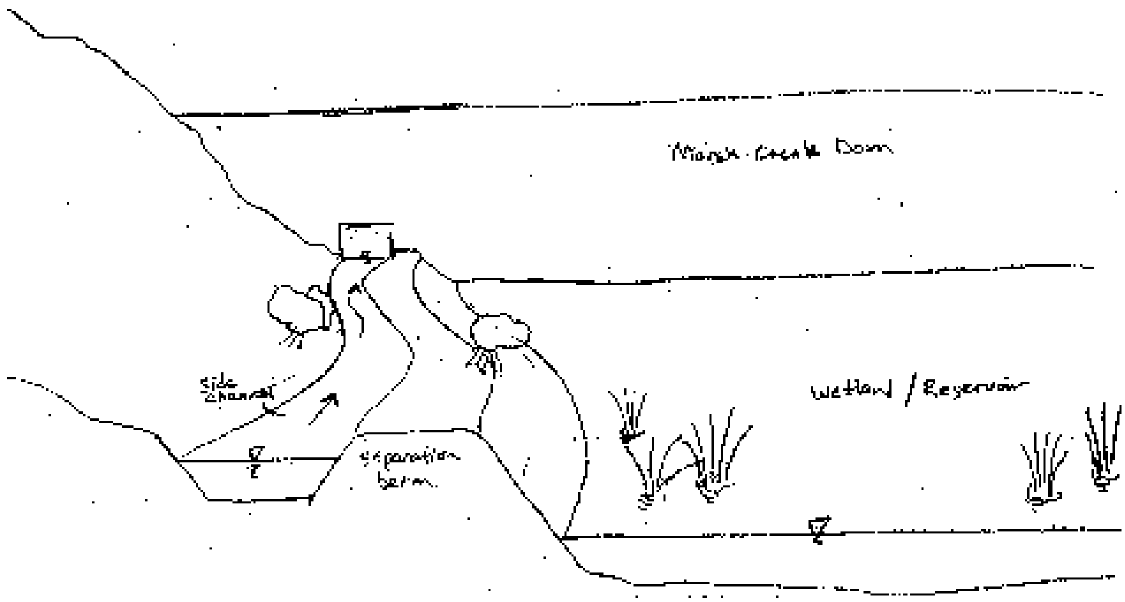

Figure Eight: Looking downstream at a typical cross section, with the reservoir outlet and Marsh Creek Dam in the background.

Figure Nine: Marsh Creek Dam and Reservoir existing layout.

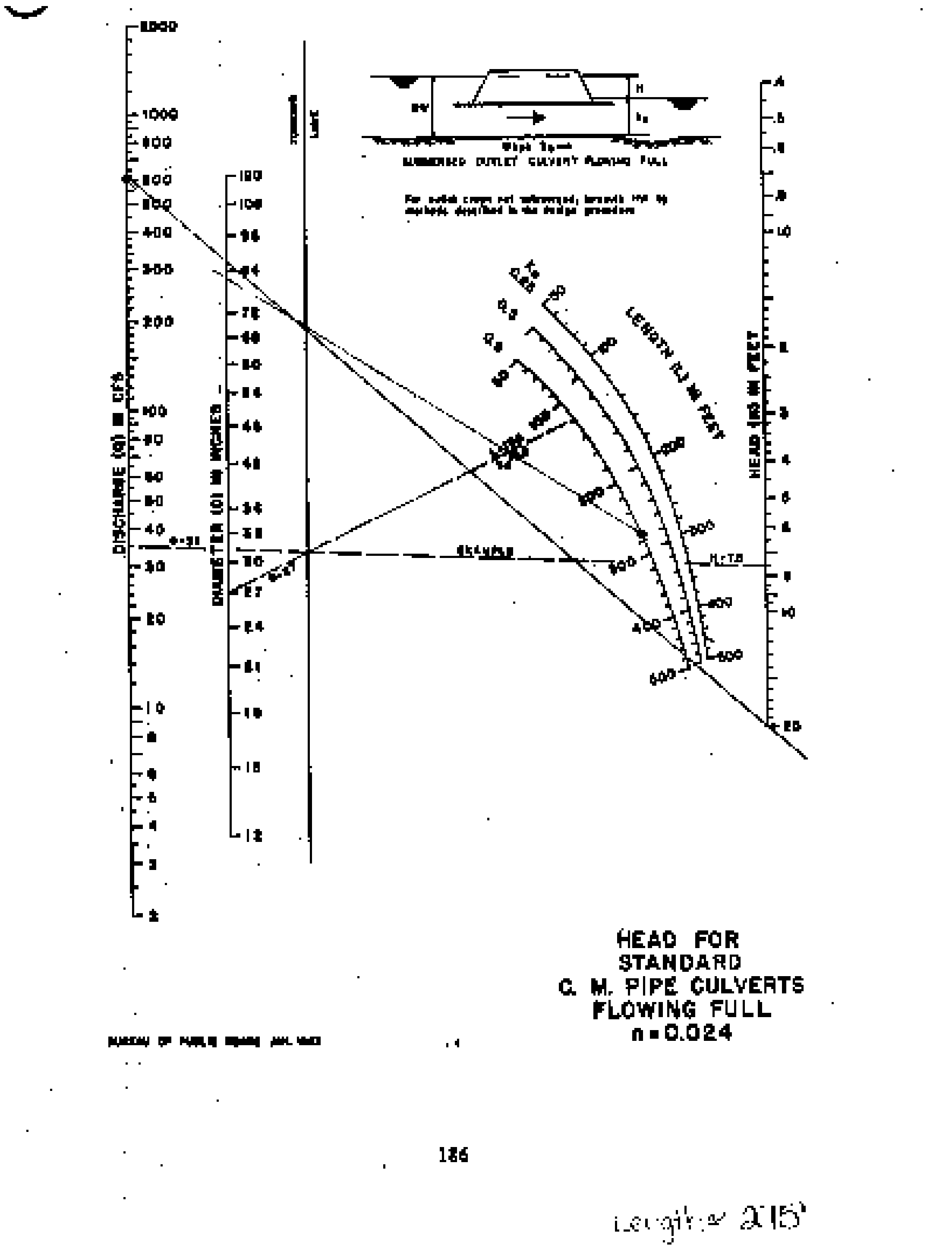

Figure Ten: Bureau of Public Roads culvert sizing chart.

Figure Eleven: Downstream reach of Marsh Creek. Note lack of riparian vegetation.

Design Criteria	Design Flow (cfs)	Design Slope (ft/ft)	Average Velocity (ft/s)	Depth of Flow in Culvert (in)	Diameter (inches)
Maximum Discharge (20' of head)	598	n/a – pressure flow	n/a	n/a	84
Fish Passage High Flow	190	.003	3.1	98	108
Fish Passage Low Flow	3	.005	1.16	12.4	48

Table 1: Results, using Flow Master and Bureau of Public Roads Chart 6, of various culvert design parameters.