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Lake Champlain Basin Program

Hydrologic Modeling and Conceptual Siting Analysis for the Evaluation of a Barrier to Control the Sea Lamprey Population of the Pike River and Morpion Stream, Québec, Canada

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Hydrologic Modeling and Conceptual Siting Analysis

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the Pike River and Morpion Stream, Québec, Canada

La modélisation hydrologique et l'analyse d'emplacement conceptuelle pour l'évaluation d'une barrière pour contrôler la population de lamproie marine dans la rivière aux Brochets et le ruisseau aux Morpions au Québec, Canada

BY

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Executive Summary

This report, funded by a grant from the Lake Champlain Basin Program and the United States Environmental Protection Agency (IAG DW-14-94028201-0), was commissioned in response to the determination of two prior reports (Walrath and Swiney 2001; Dean and Zerrenner 2001) that construction of a weir on le Ruisseau aux Morpion (Morpion Stream), a tributary to le Rivière aux Brochets (Pike River), was currently the most feasible and acceptable method for reducing the production of sea lamprey from the Pike River watershed. Walrath and Swiney (2001) evaluated the costs, impacts, effectiveness, and acceptability of various sea lamprey control methodologies for the Pike River and Morpion Stream. Dean and Zerrenner (2001) conducted an extensive sampling survey on the Pike River and Morpion Stream to provide larval lamprey population estimates. Dean and Zerrenner (2001) concluded that the majority of sea lamprey in the Pike River watershed was the result of reproduction and rearing that occurs in Morpion Stream. In accordance with recommendations for appropriate control techniques reported by Walrath and Swiney (2001), U.S. and Québec natural resource agencies agreed that an adjustable-crest weir on Morpion Stream was currently the best solution for addressing the problem of sea lamprey production from the Pike River watershed. This report explains the rationale for a weir, the plans for its construction, means of its operation, its potential floral and faunal impacts, and its anticipated impact on sea lamprey production.

Based on the attributes of Morpion Stream, engineering possibilities, consultation with professionals familiar with weir designs, and the need to construct a lamprey barrier with the least possible impact on the ecosystem, four weir designs were considered. Three barrier types with crests and a flow-through screen barrier were proposed, each exhibiting differing and specific favorable and unfavorable attributes. These weirs all incorporate a fish trap to collect and sort fish for either transport above the barrier or removal in the case of sea lamprey. All four proposed designs are only in place and operation during a 3-month period of the year and when used with the traps, ensure a limited amount of disruption to the aquatic community while preventing sea lamprey from spawning in Morpion Stream. The selection of one of these designs will enable the Lake Champlain Fish and Wildlife Management Cooperative to construct a weir that will help to eliminate the substantial contribution of sea lamprey to Lake Champlain that Morpion Stream currently provides.

Sommaire Exécutif

Ce rapport, financé par une subvention du Programme de mise en valeur du bassin du lac Champlain (*Lake Champlain Basin Program*) et de l'Agence de protection environnementale des Etats-Unis (*United States Environmental Protection Agency*) (IAG DW-14-94028201-0), a été réalisé en réponse à la conclusion de deux rapports précédents (Walrath et Swiney 2001; Dean et Zerrenner 2001) soit que la construction d'un barrage sur le ruisseau aux Morpions, un tributaire à le rivière aux Brochets, était actuellement la méthode la plus réalisable et la plus acceptable pour réduire la production de la lamproie marine du bassin versant de le rivière aux Brochets. Walrath et Swiney (2001) ont évalué les coûts, les impacts, l'efficacité, et l'acceptabilité de diverses méthodologies pour le contrôle de lamproie marine pour le rivière aux Brochets et le ruisseau aux Morpions. Dean et Zerrenner (2001) ont conduit une campagne d'échantillonnage extensive sur le rivière aux Brochets et le ruisseau aux Morpions pour évaluer la production larvaire de lamproie. Dean et Zerrenner (2001) ont conclu que la majorité de la lamproie marine dans le bassin versant de la rivière aux Brochets était le résultat de la reproduction observée dans le ruisseau aux Morpions. Selon les recommandations de Walrath et Swiney (2001) pour les techniques de contrôle appropriés, les États-Unis et le Ministère des ressources naturelles et faunes du Québec ont convenu qu'un barrage submersible et réglable sur le ruisseau aux Morpions était actuellement la meilleure solution pour gérer le problème de la production de lamproie marine dans le bassin versant de la rivière aux Brochets. Ce rapport explique la justification pour un barrage, les plans pour sa construction, son opération, ses impacts potentiels sur la flore et la faune et son impact prévu sur la production de lamproie marine.

Basé sur les caractéristiques du ruisseau aux Morpions, les considérations technologiques, les consultations auprès de professionnels experts en conception de barrage et la nécessité de construire une barrage avec le moins d'impact possible sur l'écosystème, il y avait quatre concepts de barrages considérés. Nous avons passé en revue trois types de barrages avec des tailles réglables et un barrage avec un écran par lequel l'eau passe. Chacun des quatre types de barrage possède des caractéristiques semblables et différentes, favorables et défavorables. Tous les barrages proposés incorporent un piège de poissons qui rassemblerait les poissons pour être transporté au-dessus du barrage ou, dans le cas de la lamproie marine pour être enlevé du ruisseau. Tous les concepts proposées seront seulement en place et fonctionnel pendant trois mois par an, assurant une perturbation minimale à la communauté aquatique mais empêcheront également la lamproie marine de se reproduire dans le ruisseau aux Morpions. Le choix d'une conception de barrage permettra à la Coopérative de Gestion de Poissons et de Faune du lac Champlain (*Lake Champlain Fish and Wildlife Management Cooperative*) de construire un barrage qui réduira la contribution substantielle de la lamproie marine au lac Champlain en provenance du ruisseau aux Morpions.

1.0 Background

Recent rates of predation by sea lamprey (*Petromyzon marinus*) on the fishes of Lake Champlain are higher than have ever been recorded. Data from 2003 showed a rate of 92 lamprey wounds per 100 lake trout. During the 8-year experimental lamprey control program on Lake Champlain (1990-1997), wounding rates were decreased through control efforts by roughly one third to one half of their previous numbers (Fisheries Technical Committee 1999). Lamprey control efforts were not implemented in Quebec during the experimental program and since then the contribution of sea lamprey production from Quebec tributaries to Lake Champlain has remained uncontrolled.

The Pike River watershed is a known producer of sea lampreys (Dean and Zerrenner 2001). The Pike River from its mouth to the dam at Notre-Dame-de-Stanbridge provides 13.2 km of both spawning and rearing habitat for sea lamprey. Morpion Stream, which enters the Pike just below the dam at Notre-Dame-de-Stanbridge, provides even more suitable lamprey spawning and rearing habitat. Sea lamprey spawning and rearing have been documented throughout its 29.5 km length up to its source, near Béranger, Quebec (USFWS, unpubl. data 2004; Dean and Zerrenner 2001). The original survey of the Pike River watershed produced an abundance estimate of 55,671±27,317 (95% C.I.) ammocoetes from the wadable Pike River mainstem and 76,595±48,182 (95% C.I.) ammocoetes from Morpion Stream. Based on population age structure differences between ammocoetes from the Pike River and Morpion Stream (Dean and Zerrenner 2001), it is believed that the majority of lamprey production in the Pike River watershed originates from lampreys that spawn in Morpion Stream.

An additional ammocoete survey was performed on Morpion Stream during the summer of 2004 to confirm the estimated population reported by Dean and Zerrenner 2001. The 2004 survey returned a population estimate of 139,809±131,142 (95% C.I.) (Appendix A) and showed the same length-frequency distribution pattern (Figure 1) as seen by Dean and Zerrenner 2001. The method used to calculate confidence intervals for the 2004 estimate incorporates habitat variability, thus resulting in wider confidence bands. Although the confidence intervals are broad for the population estimates, the mean densities of ammocoetes per square meter increased from 2.47±0.62 (S.E.) in 2001 to 4.10±0.87 (S.E.) in 2004. The apparent implication from these surveys is that the production of lamprey in Morpion Stream has substantially increased during just the past three years. This increased rate of lamprey production also coincides with an increasing rate of wounds on lake trout measured since the end of the 8-year experimental program in 1997 (Figure 2). The Pike River watershed is a major producer of lamprey in the Lake Champlain Basin; relative to estimates from other Lake Champlain Basin watersheds, its larval production ranks third behind only the Great Chazy and Saranac rivers of New York State. Unlike the Pike River watershed, lamprey populations in the Great Chazy and Saranac Rivers are currently controlled chemically to prevent parasitic-phase sea lamprey from entering Lake Champlain.

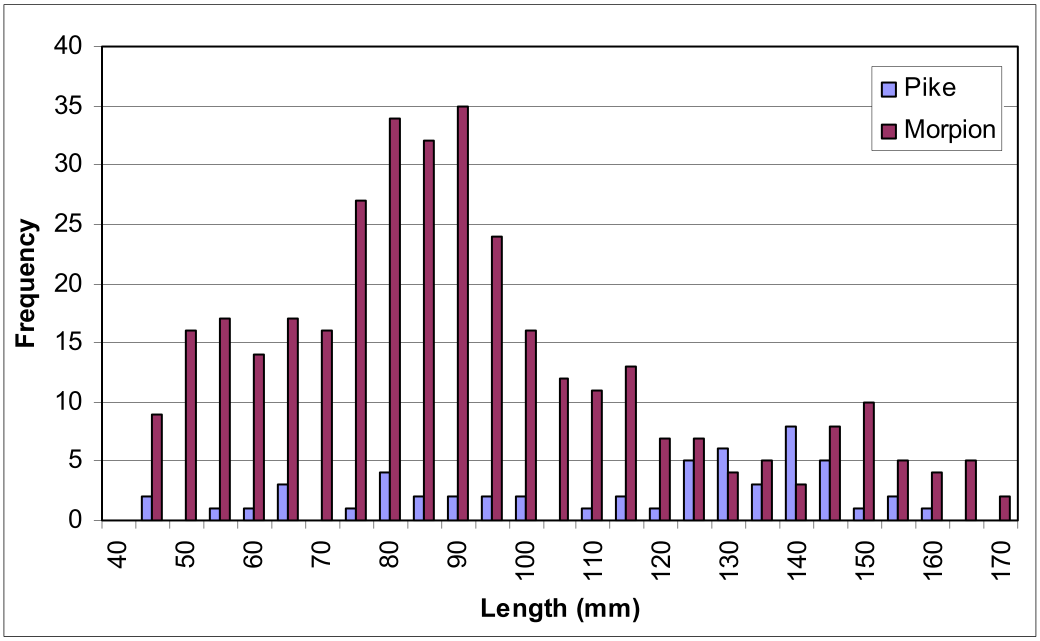

Figure 1. Length-Frequency catch data from the year 2004 are shown for both the Pike River and Morpion Stream.

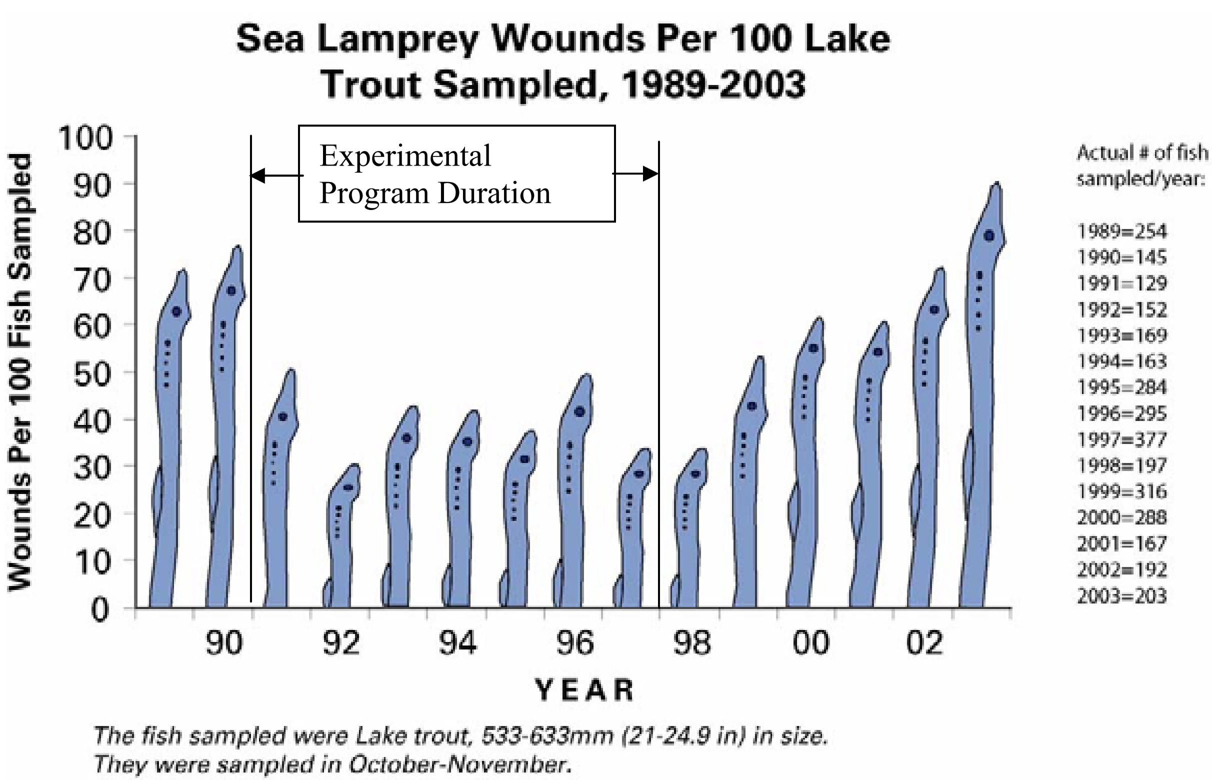

Figure 2. Lake trout wounding data is shown from Lake Champlain before, during, and after the 8-year experimental program.

The Fisheries Technical Committee of the Lake Champlain Fisheries and Wildlife Management Cooperative has identified lamprey control in the Pike River watershed as imperative to the success of sea lamprey control in Lake Champlain. Lamprey that rear in the Pike River system were known to parasitize fish in Missisquoi Bay, but have recently been found in the Main Lake and Inland Sea portions of Lake Champlain (Howe and Marsden unpubl. data). These recent findings establish that sea lamprey production from the Pike River System has a basin-wide, not localized effect on Lake Champlain fisheries.

The basin-wide lamprey problem is potentially compounded by the phenomenon of compensatory survival of sea lamprey populations. Lamprey control is not a zero-sum-loss strategy, meaning that effective control in 90% of the basin does not necessarily equate to a 90% reduction in adult sea lamprey populations. Areas that are not controlled can potentially compensate for those areas that are controlled, and may negate to varying degrees the effort expended in control (Jones et al. 2003). Years of lamprey wounding data indicate that one or more areas of the Lake Champlain Basin are not being effectively controlled and are serving to continually replenish the partially controlled lamprey population. The Pike River watershed is one of these uncontrolled systems and contains one of the highest estimated larval populations in the basin. Even a single, uncontrolled, high-producing lamprey source can have substantial lake-wide effects on fish wounding (Wells 1980). Until the production of sea lamprey from the Pike River watershed is addressed, control efforts may never achieve more than limited success.

The two most effective means of control for sea lamprey are chemical pesticides and migratory barriers. The Pike River mainstem already has a barrier located in the municipality of Notre-Dame-de-Stanbridge, but the unimpeded portion of the Pike River and Morpion Stream still provide almost 43 km of spawning and rearing habitat for sea lamprey. The Province of Quebec opposes the use of aquatic pesticides (Gagnon 2002), but is more willing to explore a proposed weir on Morpion Stream. If a weir can be constructed near the mouth of Morpion Stream, the amount of available habitat will be decreased from 43 km to 14 km. Morpion Stream has preferable rearing habitat and a more dense larval population which may result in a greater proportional reduction in lamprey production if controlled. However, if animals are forced to spawn elsewhere in the Pike River, below both barriers, we may see increases in Pike River densities. Nevertheless, the construction of a weir serves to better contain the population and allow for more focused control efforts in the future.

2.0 Site Description

Morpion Stream flows approximately 29.5 km from near Béranger, Quebec, to its confluence with the Pike River in Notre-Dame-de-Stanbridge (Figure 3). The source of Morpion Stream is indeterminate, but appears to be a series of small springs in a low-lying area, west of Béranger. There are no known natural or constructed barriers currently in Morpion Stream, thus migratory species have access to its entire course.

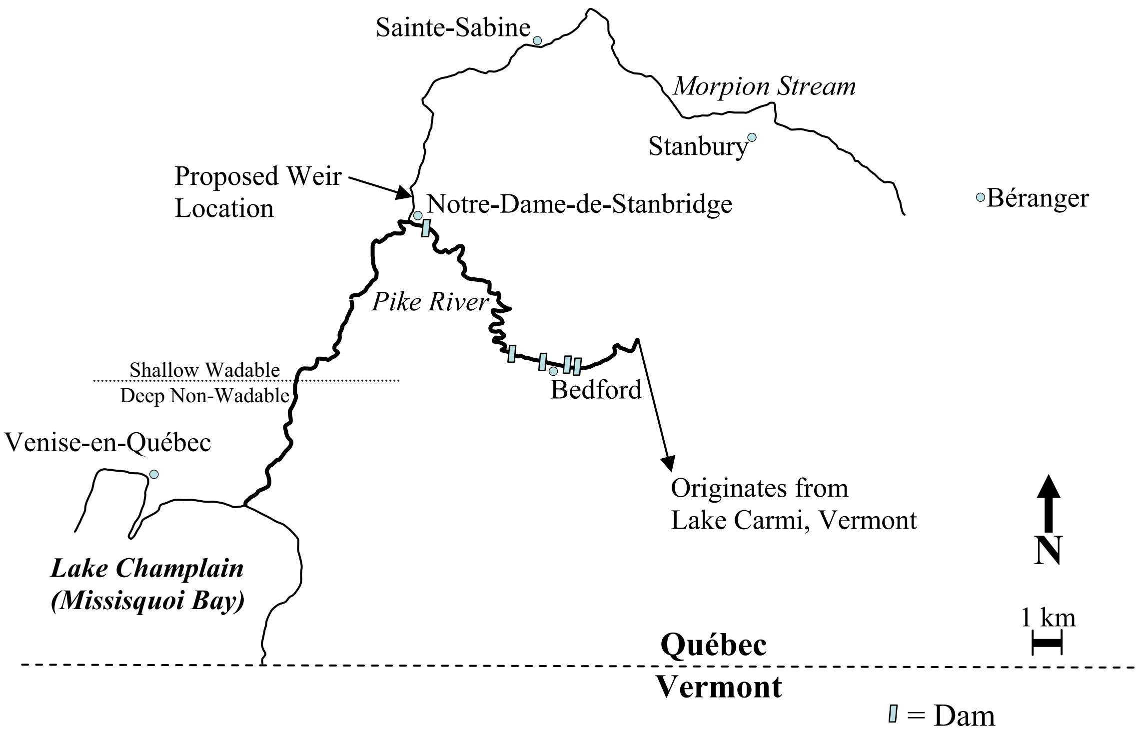

Figure 3. The map shows the sea lamprey spawning and rearing habitat for the Pike River below the dam at Notre-Dame-de-Stanbridge and throughout Morpion Stream in the Pike River watershed. Location of the proposed weir site is indicated.

2.1 Topography and Geology

Morpion Stream is a low-gradient stream throughout its entire course. Its mean width is approximately 3 meters (Dean and Zerrener 2001) while its maximum width occurs near its mouth where it is about 9 meters wide (USFWS unpubl. data 2004). The upper half of Morpion Stream is dominated by riffle – pool – glide habitats and is more sinuous than the lower half which appears to have been channelized near Notre-Dame-de-Stanbridge (Figure 4). The lower half is more continuous glides with occasional constrictions forming some riffles along this low-gradient section. Substrate in the upper half is dominated by cobble, gravel, and boulder. Fine to coarse sand is found in the interstitial and depositional areas. The lower half of Morpion Stream, especially the lower quarter, is dominated by more clay deposition throughout its channel. While many substrate types are present, the dominant type in this slower-moving section is silt and clay. Habitat for both adult spawning and larval rearing is present throughout the entire course of Morpion Stream.

Looking Upstream from Bilodeau Bridge

Looking Downstream from Bilodeau Bridge

Figure 4. The channelized lower section of Morpion Stream is shown above and below Bilodeau Bridge. The furthest visible water in the downstream view is the confluence with the Pike River.

2.2 Land Use and Water Quality

The entire Pike River watershed is under the influence of intensive agricultural uses. Corn, hay, straw, pasture, or feedlot pens border the majority of Morpion Stream's banks. Some areas have substantial riparian buffer strips while others are farmed to the edge of the bank. Morpion is used for irrigation by local farmers who pump straight from the stream. The most recent water chemistry data from Morpion Stream are from 1994-1996 reports when normal conditions were recorded for pH and alkalinity, but relatively low dissolved oxygen values were recorded (Vermont Dept. Fish and Wildlife unpubl. data). Although water quality has improved since then, surrounding land use practices and their density in the watershed are still consistent with less than optimal water quality conditions. The observed summer fish community, dominated by cyprinid, catostomid, and ictalurid species, is also consistent with less than optimal water quality. Although the water quality may be lower than desired, it is perfectly amenable to sea lamprey as their high densities were relatively equal throughout Morpion Stream.

3.0 Weir Construction

3.1 Siting

The proposed weir has been planned for a point approximately 150 meters upstream of the Pont Bilodeau (Bilodeau Bridge). This is the first bridge upstream from the confluence of Morpion Stream with the Pike River. The weir would be approximately 333 meters upstream from the confluence and 61 meters downstream of the first bend above Bilodeau Bridge (Figures 3 and 4). The bank elevation above sea level is 41 meters at this site. The site was chosen for its ease of access and its channel morphology attributes. At this site and above it in the proposed impoundment zone, the banks of Morpion Stream are approximately 2-2.5 meters higher than the bottom of the channel. These high (relative to the rest of Morpion Stream) and steep banks will reduce the surface area of any impoundment. The low gradient of Morpion Stream results in a longer distance of impoundment than would be seen in higher gradient streams. The expected distance of impounded stream behind the weir is 1,111 m based on a surveyed slope of 90 cm/km. This is the estimated impounded distance when the weir crest height is set to 1 meter.

3.2 Weir Designs

Five weir designs were considered for this report, each one having specific benefits and detriments. All weir designs would incorporate a fish trap to mitigate fish passage while the biggest differences among designs are attributable to permanency, cost, ease of operation, potential to flood surrounding lands, and effectiveness in blocking lamprey migration. The characteristics of the different weirs are presented in the following sections, but direct comparisons between designs are reserved until section 3.3.

3.2.1 Fixed Crest

Fixed crest barriers are used frequently in the Great Lakes sea lamprey control program. Their usage is intended not only to prevent migrating sea lamprey from spawning, but also to reduce the miles of stream that need to receive lampricide treatment (Lavis et al 2003). A fixed crest weir would require poured concrete or steel sheet-piling be installed permanently in Morpion Stream. The fixed crest design would be an effective barrier to lamprey, however it would block all other species as well, during every day of the year (save those tended from the trap). The province of Quebec has made it clear that they will not consider permitting the construction of a permanent structure like this. Quebec requires that any structure installed must either be removable or adjustable in its design to allow the river to flow freely when lamprey migration has ceased. This Quebec provincial requirement, only allowing seasonal operation of any proposed barrier, precludes any further consideration of building a fixed crest barrier on Morpion Stream.

3.2.2 Manual Variable Crest (MVC)

The MVC is a useful weir system that can allow passage of jumping species while preventing passage of lampreys. It is designed to function like a fixed crest barrier, but with the added advantage of enabling control of crest height. Crest height variation is manipulated using inflatable bladders that when filled or evacuated serve to raise and lower the surface that holds back water (Figures 5 and 6). The distance between the lip of the crest and the pool below needs to be maintained at or above 30 cm of elevation to prevent lamprey from breeching the barrier (Lavis et al. 2003; Hunn and Youngs 1980). The MVC can be controlled on-site at a station where the elevation can be adjusted by a trained operator. With a MVC design, operators cannot be expected to attend to the barrier at all times of the day and night to make adjustments to maintain the 30-cm spill elevation. Therefore, the MVC would usually be set far above the 30-cm minimum elevation to accommodate for times when high discharges raise the pool elevation below the barrier. Adjustments could be made by the operator when necessary, especially if extreme discharge events threaten to flood the impounded area. Although the ability to manipulate crest height is not as useful on a real-time scale with the MVC, it has the benefit of being able to be lowered flat against the channel bottom when not in service. That would allow for the river to flow freely with no impoundment or impedance.

Because the primary reason for installing a variable crest weir is to facilitate the natural movement of migrating salmonid or other jumping species, its use in Morpion Stream would be less applicable. The weir is designed to be adjustable in response to discharge and provide a constant spill elevation that can be leaped over by jumping species. Morpion Stream has no record of spawning salmonids or other migratory species that would jump over a weir. With or without a variable crest design, migrating species in Morpion Stream would necessarily need to be lifted over the weir using the built-in trap.

3.2.3 Automated Variable Crest (AVC)

The AVC is an advanced form of the MVC. The instream physical structure of the AVC is identical to the MVC, but the manipulation of crest height is automated or remotely controlled (Figures 5 and 6). Whereas it takes an operator on site to adjust the crest with a MVC, the AVC incorporates a computer system that monitors stream stage height at the site and uses a site-specific algorithm to calculate how high the crest needs to be raised to achieve the 30-cm elevation difference. Like the MVC, the AVC can be made to lay flat when fully deflated, thus allowing the stream to flow freely when lamprey are not migrating. Perhaps the biggest benefit that the AVC would provide in

Morpion Stream is the ability to monitor and adjust the crest height remotely. The automatic stage monitoring system can be overridden remotely at a computer terminal. This would allow adjustments and 24-hour monitoring capabilities that would be too cumbersome for an individual to assume.

Figure 5. The instream structures used for both manual (MVC) and automated (AVC) variable-crest weirs. This AVC is in operation on the Big Carp River in Sault Sainte Marie, Ontario. The lamprey trap is shown on the left. The crest height can be raised or lowered as needed.

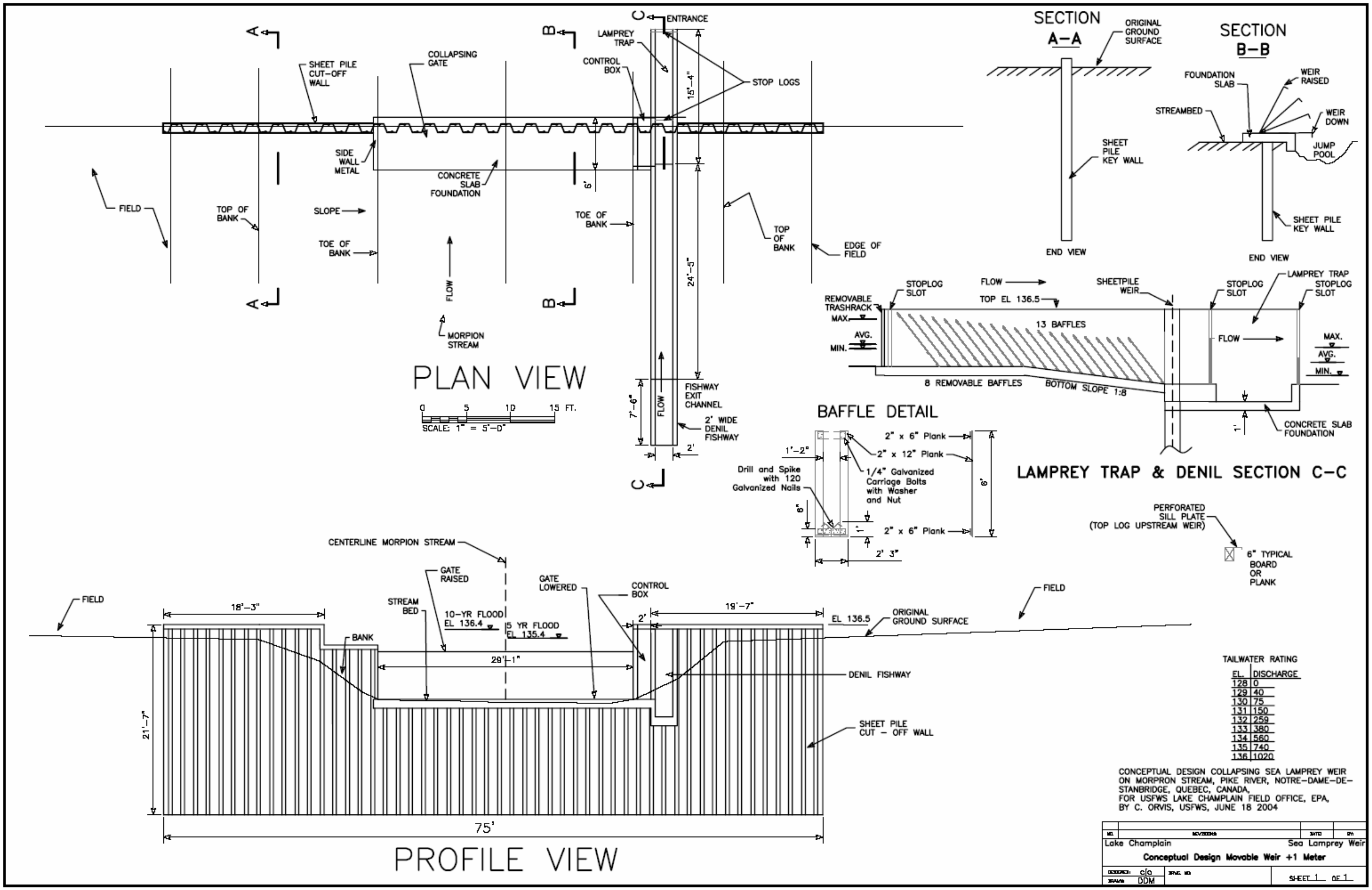

Figure 6. Size-reduced engineered drawing of the instream structure used for both a manual variable crest (MVC) and an automated variable crest (AVC) weir design. A fish trapping structure would be placed where the current fishway is shown. Full-sized drafting plots are available in AutoCad format.

3.2.4 Seasonal Variable Crest (SVC)

This design is a conventional stop-log weir that is operated as a seasonal variable-crest (SVC). The crest variability in this design is not automated, it is controlled by how the stop logs (lumber beams) are stacked within the sluice (Figure 7). Crest height can be set at zero by removing all stop logs or as high as 1.2 meters above mean annual flow stage. Vertical piers used as anchor points to hold the ends of the stop logs can be either steel or concrete and set 1-2 meters apart (Figure 8). Steel piers could be removed with heavy equipment, but concrete piers would remain in the stream after stop logs are removed. If the concrete piers were left in place, they would not impede the free flow of the river unless large woody debris piled against them. The crest height is fixed during the migration season using this design, but the difference in spill elevation between the impoundment and river stages decreases as flows increase. The 30-cm spill elevation is also needed when using this design to prevent lamprey migration.

Figure 7. A seasonal variable-crest weir in operation using gates rather than stoplogs. The Morpion Stream design differs from the weir pictured in that it does not include the walkway, railing, or gate control structures. The midstream piers could be constructed with steel and removed when the weir is not in operation.

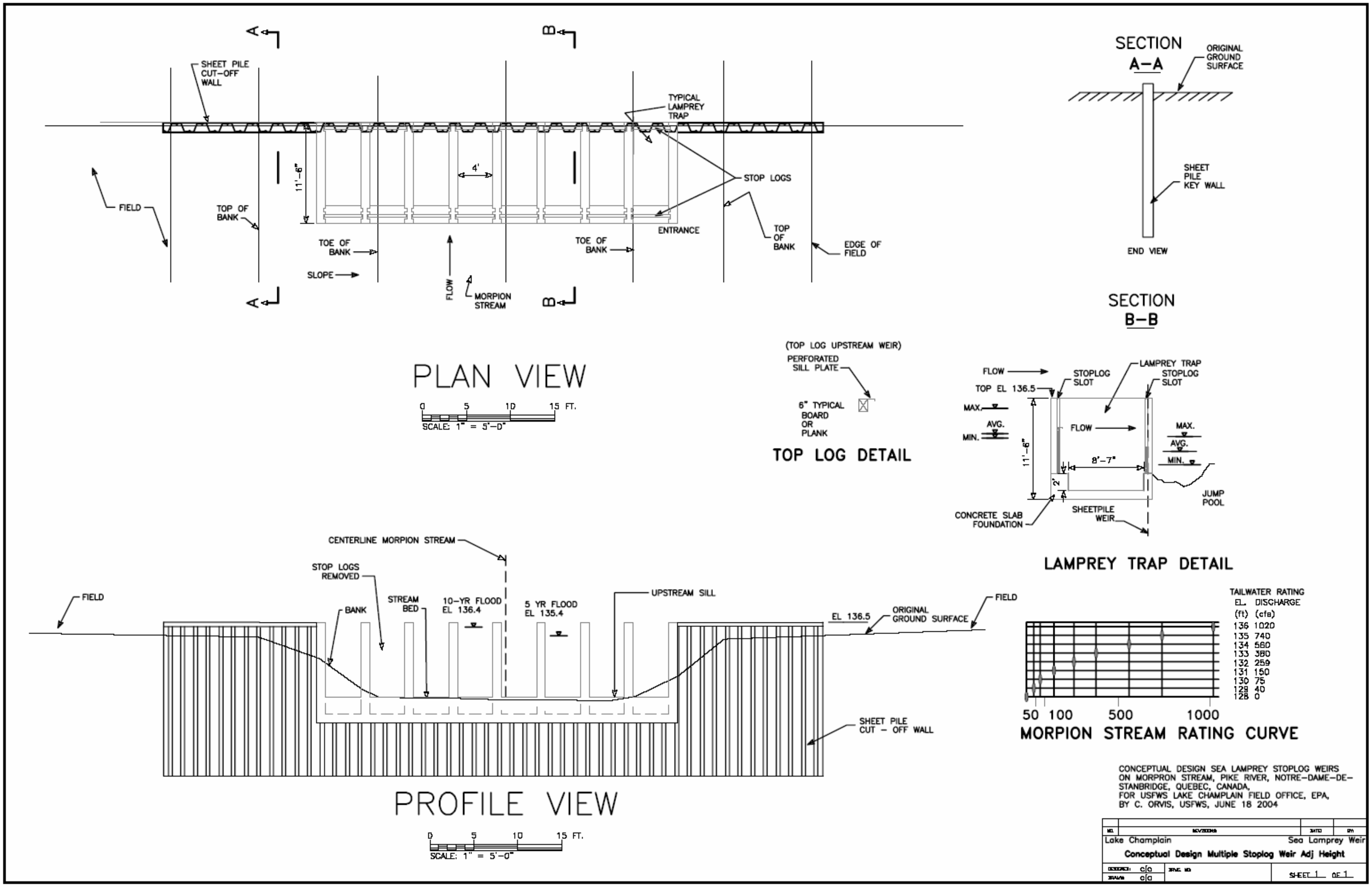

Figure 8. Size-reduced engineered drawing of the proposed seasonal variable-crest weir. Full-sized drafting plots are available in AutoCad format.

3.2.5 Flow-Through Screen (FTS)

The FTS is not a true dam because it does not force the flow of water to be completely impounded before spilling over a crest (Figure 9). Instead of an impermeable surface that forms a crest, the FTS relies on stainless steel screen with mesh small enough to prevent adult lamprey from migrating through it. The mesh is large enough that it allows smaller organisms to pass through, both up and down stream. The mesh is stretched across panels which would slide between stationery A-Frame supports, spaced 2.5 meters apart (Figure 10). The screens and A-Frame structures are both removable and will leave the stream free of impediments after lamprey spawning season. For adult sea lamprey, a 19-mm mesh is proposed that, when accounting for the diameter of the screen fabric, yields about a 16-mm opening. This size will adequately block all migrating adult sea lamprey, but allows most invertebrates and small fishes to pass through. The key feature of the FTS is that it avoids producing a hydraulic head like all the other barriers. Water is only impounded slightly during high flows where experience has shown a difference of less than 20 cm during floods. The only real impoundment occurs if or when debris clogs the mesh sufficiently to force the flow to back up and potentially spill over the top of the barrier. This condition is quickly alleviated by cleaning the screen and restoring the flow-through nature of the barrier.

Figure 9. A flow-through screen barrier used in Maine to collect Atlantic Salmon (*Salmo salar*). The flow-through screen structure on Morpion Stream would be a single diagonal design rather than the "V-Shape" pictured here. The lower gradient lends itself better to the screen design and prevents the buildup of a hydraulic head upstream of the weir where flooding could be a concern.

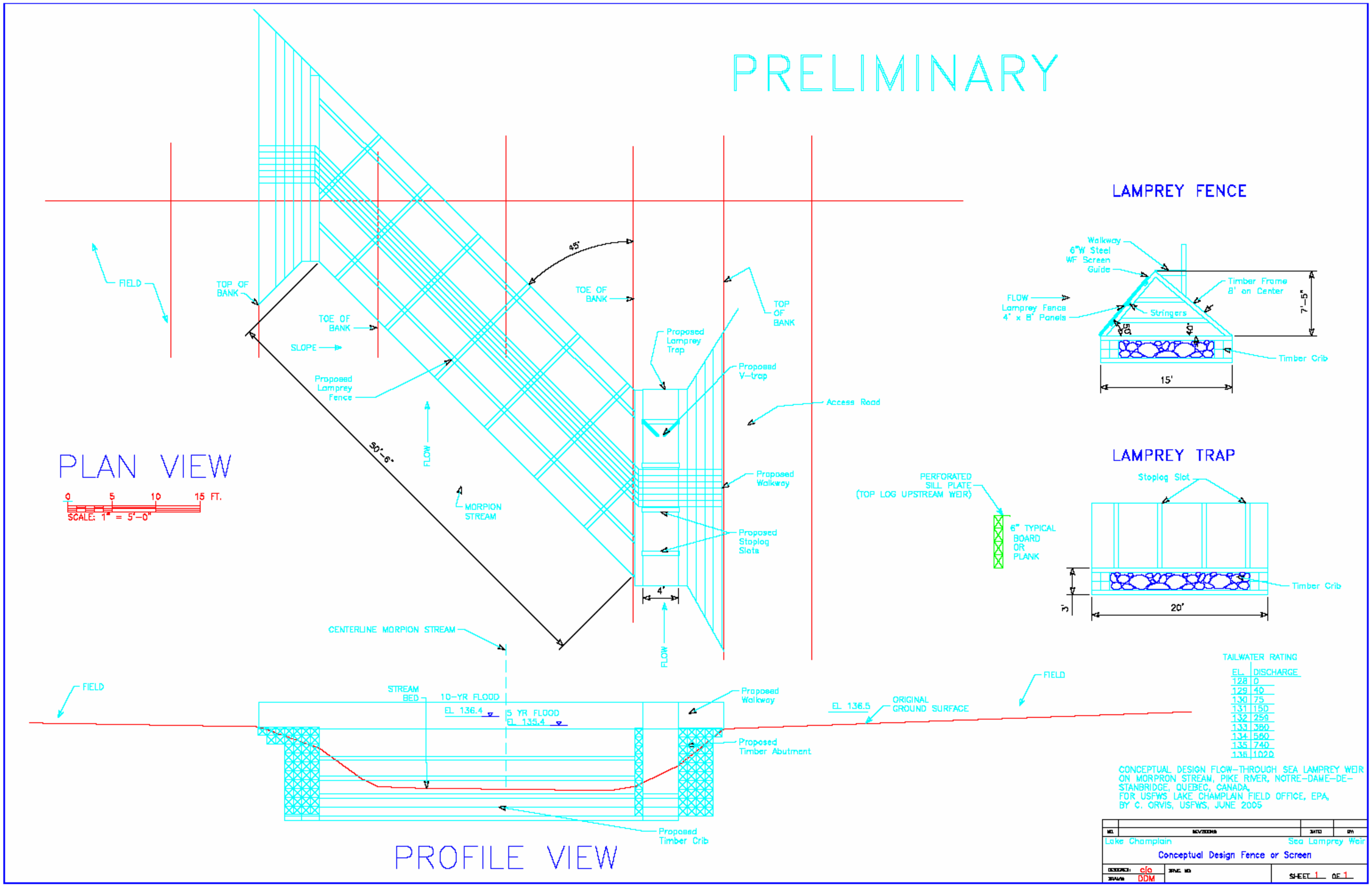

Figure 10. Size-reduced engineered drawing of the proposed flow-through screen weir. Full-sized drafting plots are available in AutoCad format.

3.3 Comparison

Specific criteria important for use in evaluating the effectiveness and feasibility of each barrier and trap are shown and rated in Table 1. The justification for these ratings and details surrounding the performance of each barrier type as evaluated in the table appear in the subsections below.

Table 1. The four potential weir designs are compared based on the criteria in the table. Where appropriate, criteria are rated from 1 to 10 with 1 being unacceptable and 10 being outstanding. MVC=Manual variable crest; AVC=Automated variable crest; SVC=Seasonal variable crest; FTS=Flow-through screen

	MVC	**AVC**	**SVC**	**FTS**
Flooding Avoidance	3	5	3	9
Impoundment Effects (reduces)	4	4	3	9
Impediments left in stream during off-season (fewest)	8	8	5	6
Downstream Erosion Avoidance	5	5	5	9
Sedimentation (prevents retention and release)	5	5	5	9
Effective Lamprey Blocking	5	5	5	8
Fish Passage Mitigation	8	8	8	8
Reliability	5	5	8	8
Ease of operation	5	6	9	3
Ease of seasonal setup and take-down	9	9	4	5
Cost (least expensive)	4	3	9	8
Sum	*61*	*63*	*64*	*82*

3.3.1 Hydrology – See appendices B and C for details on hydrological determinations

MVC - The MVC will impound water, in its fully upright position, for 1.1 km. The impoundment height will lower if and when the crest height is lowered. At the end of the season, the barrier will be deflated and no water will remain impounded. With a 1-m raised crest, pool elevation behind the crest will be 0.4 m below bankfull elevation (136 ft or 41 m) at normal base flows for April and May (Figure 11). A 1-year flood event would be less than 10 cm from reaching bankfull and a 2-year flood event would exceed bankfull stage (Figure 12 and Appendix C). A 0.75-m crest height would yield a pool elevation 0.67 m below bankfull elevation at normal flows, 0.3 m below bankfull at a 1-year flood stage, and exceed bankfull during a 2-year flood (Appendix C, figure C-30). A 1-m crest height would retain the 30-cm spill differential during a 1-year flood, but not during a 2-year flood. A 0.75-m crest would lose the minimum 30-cm differential during a 1-year flood event.

A 1-year flood event, assuming to occur on average, only once each year, is most likely to occur in February or March as ice and snow melt and stream levels rise. Flood events with a 1-year to10-year periodicity rating are less likely to occur during lamprey spawning season, but certain to happen at some time. Designing a barrier with 1-year flood event “protection” against lamprey migration is consistent with risk accepted by Great Lakes barrier operators (Andrew Hallett, DFO, pers. comm.). A barrier with a trap is also more likely to capture migrating lamprey which is far easier for them to enter rather than enduring high flows to breach the crest. Less risk of lamprey passage is preferable, but because flooding is a concern, any higher than a 1-m crest would approach flood stage during even normal spring hydrologic variation.

Much of the surrounding land is agricultural and ditched in some cases to promote drainage. The numerous fields and potential tile drains have not been specifically surveyed to evaluate whether impounded water would back into these areas or not. However, if the pool elevation behind the crest will be raised to within 40 cm of bankfull under base flow conditions, then the probability is high that any surrounding lands that are ditched into Morpion Stream or use tile drains into Morpion Stream would serve as reverse conduits to deliver water back to these areas more frequently than would have been seen in past experience. However, note that these occurrences would be situational based on weather-related flow events. The presence of the barrier would not cause inundation or poor drainage during the entirety of its operation period.

During the off-season, no significant structures will be left in the channel that would affect flows. The crest would be lowered and form a flat strip of metal and concrete along the base of the stream channel from bank to bank.

AVC – The AVC is exactly the same as the MVC in every respect except that it can be operated remotely or programmed to respond automatically. If a flash-flood event were to occur in the middle of the night, there would not be time to respond to the MVC and lower it to alleviate flood potential. However, the AVC could be programmed or overridden to respond in real-time to such an event. The hydrologic advantage to the AVC is attributable to “damage control” if needed.

SVC - The SVC is identical to the MVC and AVC with its hydrologic characteristics. The only difference is that removal or addition of stoplogs is required to alter crest heights. This makes it slightly more difficult to operate and respond to than the MVC. During the off-season, depending upon final engineering design, steel or concrete piers which serve as the anchor points for the stop logs during operation may need to be left in place. These would be vertical columns left in the stream channel that would not significantly affect the hydrograph of the stream, they would only slightly reduce stream cross-sectional area and thus slightly increase velocity in their immediate vicinity. They would have no foreseeable effects on fauna.

FTS - The FTS differs dramatically from the other designs in that it does not rely on a crest height or spill elevation to block lamprey migration. Instead, there is little or no hydraulic head present as the stream passes through a mesh screen. This means that there is no impoundment and only a marginally increased risk of flooding compared to a significantly increased risk of flooding with the other designs. The FTS will clog with debris and need to be cleaned regularly to prevent flow from slowly becoming blocked behind the screen. However, experience within the Lake Champlain Basin has shown that 1-2 day cleanings are sufficient to keep the water from impounding as screens become clogged.

The timber crib that serves as the anchoring point for the A-Frame supports would be all that remains in the stream after temporary structures are disassembled for the season. This structure, flush with the streambed, would have no effect on the hydrograph during the off-season and no foreseeable effects on fauna.

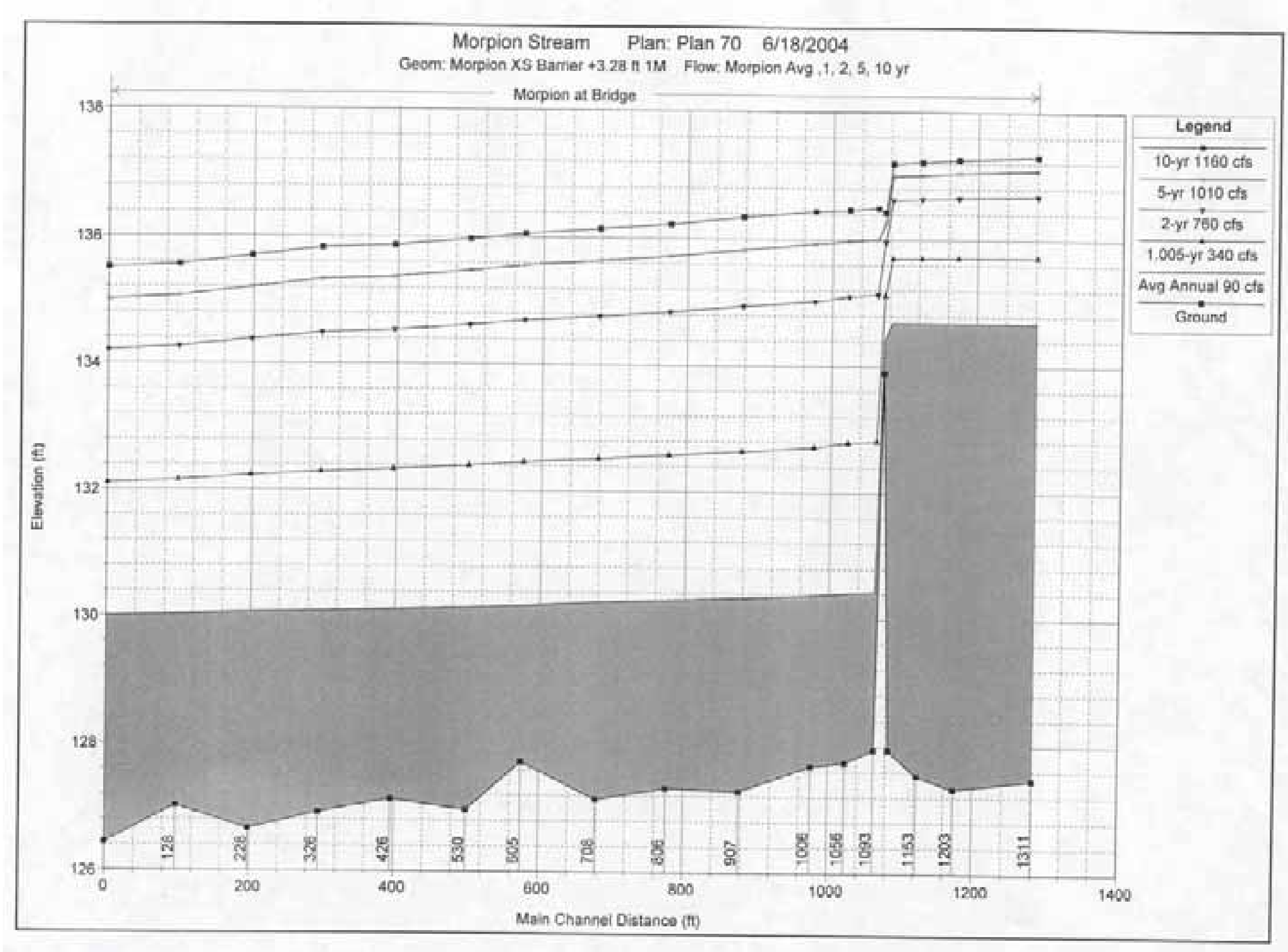

Figure 11. Projected hydrographs of Morpion Stream produced using HEC-RAS hydrological modeling software when a 1-meter crest weir is in place. Distances are reported in feet where 1 foot = 0.305 meters and 1 meter = 3.281 feet. Discharge is reported in the legend as cubic feet per second (CFS) where 1 CFS = 0.283 cubic meters per second (CMS) and 1 CMS = 35.31 CFS.

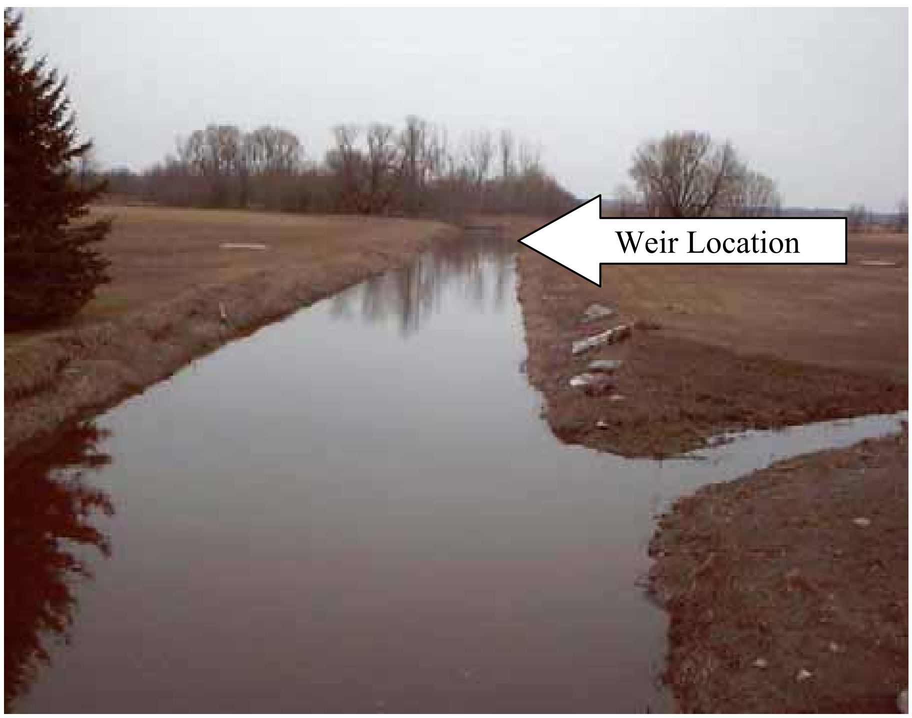

Figure 12. Pictures of Morpion Stream, standing on Bilodeau Bridge, looking upstream during different flow conditions. The upper picture was taken during the summer at base flow conditions. The lower picture was taken in March during near flood conditions. Under base flow conditions, a 1-meter crested weir would produce an impoundment, upstream of the weir, similar to the stage seen during near flood conditions in the lower picture.

3.3.2 Geomorphological Impacts

***MVC, AVC, and SVC* –** All three of these designs have relatively equal geomorphological impacts. Sediment will be stored behind the crested barriers, but the total anticipated volume or mass is unknown. The highest rate of sediment transport occurs in February or March as ice breaks and winter sediments are flushed by the high flow events associated with late winter and early spring thawing. Lamprey barriers will not be in place during this time. They will only operate for about a 3-month period, typically from early April to mid-June. Thus, because of the season of operation and the length of operation, the crested barriers will presumably retain only a fraction of the annual sediment budget of the river.

When lamprey migration season ends, the crests are lowered and the stored sediment is liberated. Research concerned with the effects of sediment liberation after dam removal is focused on structures which have years if not decades worth of sediment buildup. Most research is also concerned with dams much greater than 1 meter in crest height (See Doyle et al. 2002 for review). However, two case studies: Simons and Simons (1991) and Wohl and Cenderelli (2000) documented the movement and effects of sediments waves resulting from dam removal. Although these dams were larger and held decades worth of sediment, the sediment waves were observed to be temporary phenomena and did not cause substantial local geomorphic adjustments (Doyle et al. 2002). Additionally, sediment waves do not tend to erode channels when the wave is composed of finer grained sediment than the underlying channel substrate (Madej and Ozaki 1996). This would necessarily be the case in Morpion Stream where the extreme low gradient (90 cm/km) above the barrier prevents the transport of larger sediments. Only clay, silt, and some sand would pass over the channelized, sand-bottomed, last several hundred meters of Morpion Stream before entering the Pike River. The Pike River is a sediment-starved, high gradient, bedrock channel for all of its upper length where Morpion enters and will not be over-whelmed by the sediment load considering that is more than three times the width and discharge of Morpion Stream.

Head-cutting and channel incision at the head of the impoundment will not be an issue when drawing down the pool at the end of the season because these phenomena are in response to changes in gradient. We will not be altering gradient through either channel straightening or dredging. At the time when the crest is lowered, the change in water level will simulate the return to base flow after a high water event. The crest will be lowered at a rate of 10 cm/day for 10 days to return flows to normal levels. Flows are being restored to normal after migration season ends, they are not being diverted or altered through channel alterations.

FTS – This design practically eliminates any need to consider the effects of sedimentation or induced erosion. There is no hydraulic head produced by the FTS unless extreme debris clogging becomes an issue. Routine cleaning will prevent this from happening. The slant design may tend to direct water toward the one bank more than the other, but bank reinforcement at those points will prevent erosion caused by scouring. With no settling of sediment in an impoundment, water passing through the barrier will retain its sediment load, thereby avoiding an increase in its erosive capacity. The point of erosion that would be associated with this design would occur immediately surrounding the screens where velocity increases as cross-sectional area is reduced by the screens. Velocity quickly returns to normal after passing through the screens however.

Erosion at this small area is addressed using bank reinforcements and a timber crib which acts as a base apron where increased energy from constricted flow can be dissipated without erosional effects.

3.3.3 Effectiveness as Lamprey Barrier

MVC, AVC, and SVC – All three crested barriers are limited in their effectiveness by flood periodicity. Based on the HEC-RAS model, a maximum crest height of one meter, and a required 30-cm spill elevation, the crested barriers can be expected to be effective during 1-year flood events, but not 2-year flood events (Figure 12 and Appendices B and C). The Fish and Wildlife Service in Marquette, MI, determines effectiveness based on larval lamprey survey results. If surveys above barriers indicate that a significant enough number of larvae have been produced by adults who managed to pass the barrier that a chemical treatment is warranted as a remedial action, then that barrier is declared ineffective. Two variable crest weirs, managed by the USFWS, are in operation now where one is declared effective and the other is declared ineffective. The actual reason for why the lamprey passed the ineffective barrier is unknown, but could be flow, mechanical problems, improper crest adjustments, or other reasons. These barriers can be ineffective under multiple sets of circumstances, so erring on the side of caution is most wise when designing and operating them. The moving parts, electrical dependency, and greater complexity of the MVC and AVC offer more opportunities for mechanical failure resulting in ineffectiveness. The USFWS in Marquette still refers to MVC and AVC weirs as "experimental" control techniques. The SVC is much simpler and would experience physical failure only under a condition of collapse.

FTS – Over the course of a season, the FTS would be expected to be more effective than the other three designs. The effects of varying hydrology are of much less importance to the FTS design versus the crested barrier designs because there is no crest for lampreys to pass over. They encounter a screen with flow passing through it, not over it. This prevents them from recognizing a need to jump over an impermeable obstacle and instead, acts more like an impediment through which they will continuously search to find a passage way. That passage way will of course be our trap. The only time the FTS would be ineffective is when exceptional flows exceed the height of the screens. This would happen during flows greater than a 5-year flood event or if the screens were left clogged with debris for an extended period, creating an impounding effect. Physical barrier failure would only occur if parts of the barrier collapsed.

3.3.4 Fish Passage Mitigation

MVC, AVC, SVC, and FTC - Mitigation for all designs will be achieved by minimizing the seasonal duration of the barrier and through the use of a fish trap designed to collect and hold fish engaged in upstream movement, whether as part of a migration or normal diurnal movement patterns. The trap will be built into the weir and use increased flow velocity (greater than the main sluice) to attract fish wanting to move upstream. The trap will be a two-stage trap in which all sizes of fish in the Lake Champlain Basin [excluding large sturgeon (*Acipenser fulvescens*), never before reported in the Pike River] can be collected in the first stage. The second stage would be more size selective and allow only fish of lamprey size and smaller to enter. The purpose of this two-stage trap is to both provide a means of passing all migrating fish over the barrier and minimize the potential for lamprey escapement once they have entered the trap (Figure 13).

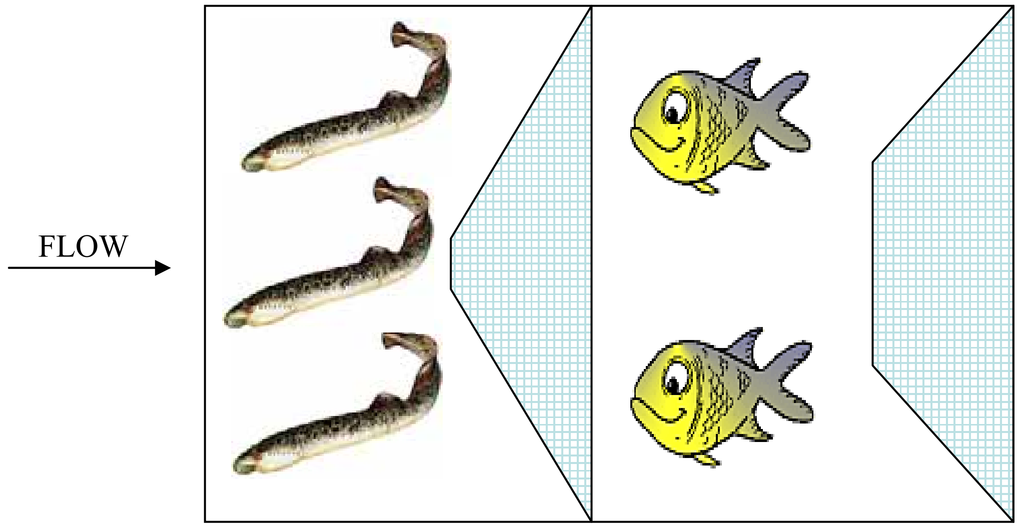

Figure 13. The conceptual design of a two-stage lamprey trap is shown

Once in the trap, lamprey will be removed from the stream and euthanized on site. All other captured fish will be lifted from the traps and released above the weir. This process would need to be completed every 2-3 days to minimize mortality of trapped fishes. This schedule has proven to be adequate in minimizing mortalities at the Great Chazy River fish trap in New York State. Experience during the last seven years has shown that mortality of all fauna trapped ranges consistently between 1% and 5% annually at sites that are trapped (USFWS, unpubl. data). The ability to pass substantial numbers of fish over the weir mitigates concern that this weir would significantly affect fish passage in Morpion Stream. Because the weir site is 88 km from the US Fish and Wildlife Service office in Essex Junction, Vermont, a local Notre-Dame-de-Stanbridge resident would be hired to tend the trap while it operated during lamprey migration season. This person would report to the U.S. Fish and Wildlife Service to provide regular updates of catches and be able to request assistance if needed. Regular tending and maintenance of this trap will ensure successful assisted passage of fish. If mortality becomes an issue of concern, frequency of trap attendance can be increased as determined to be necessary.

3.3.5 Reliability – *where reliability is defined as consistent and dependable mechanical, structural, and technological operation throughout lamprey migration season.*

MVC and AVC – owing to their more complex mechanical design, with hydraulics, motors, electricity, inflatable bladders, and numerous moving pieces, these two design are considered less reliable than the SVC or FTS. Additionally, they tend to attract vandals who have disabled variable crest weirs in Ontario, even through the use of fire arms used to deflate the bladder (A. Hallett, DFO, pers. comm.). If the mechanics or operation systems fail on a MVC or AVC, the position of the crest is to deflate and lay flat on the stream bottom until fixed (0% effective against lamprey passage). This has lead to the use of multiple redundant backup systems in the Great Lakes where these types of barriers are used. If a barrier fails in the down position, it cannot be raised "lifted" by hand to lock into an up position. The weight is too great without the assistance of hydraulics and motors. Failure in the up position would be more preferable where the barrier could be dropped by hand if needed during flood conditions, yet remain intact as a lamprey barrier while in failure mode.

SVC and FTS – Because these two designs have no moving parts or associated mechanical functions, they are only prone to failure if the structural materials themselves fail or collapse. Reliability is considered to be higher for these two designs rather than the MVC and AVC for the sole reason of design simplicity.

3.3.6 Maintenance

Fish trap tending is a necessary duty that is equal among all four designs.

MVC – The MVC is easy to raise in the spring and lower in the fall. The crest is completely operated mechanically. Operation is easy using on-site controls to adjust crest height as needed.

AVC – The AVC is also easy to raise in the spring and lower in the fall. The crest is completely operated mechanically. Operation is made easiest among all designs through the use of off-site and automatic controls to adjust crest height as needed.

SVC – The weight and volume of materials needed to setup the SVC in the spring is the greatest of the four designs and likely would require several days of transporting materials each spring and summer during setup and takedown periods. It is much more difficult to adjust crest heights with the SVC as stop-logs must physically be removed or added, yet adjustments would be made infrequently so that little time need be dedicated to this aspect of operation.

FTS – The weight and volume of materials needed to setup the FTS in the spring is comparable to the SVC design and would also require several days of transporting materials each spring and summer during setup and takedown periods. The FTS design is by far the most labor intensive design and requires the operator to clean screens upon every visit to ensure flows are not impeded. Maintenance is easily accomplished with long handled brooms or brushes, but is time consuming.

3.3.7 Cost

The costs for constructing the two weir designs are presented in Tables 2 - 5. The cost of construction for the AVC design is shown in Table 2, but costs for a MVC design are not tabulated. The two designs are nearly identical except the MVC does not have the advanced electronics needed by the AVC. For this simple difference, the cost of the MVC is estimated to be $20,000 less than the AVC, attributable to the single line item of "control station". Table 3 shows the costs of constructing a SVC weir and Table 4 shows the costs of constructing a FTS weir. Table 5 shows additional indirect costs that are equal among all designs. The cost for land easements was obtained from Walrath and Swiney (2001) and was adjusted at 4% annual inflation to estimate the 2005 cost. A private environmental consultant from Quebec is proposed for hire at an estimated cost of $15,000 U.S. dollars. This consultant would serve as a bilingual liaison between the agencies involved and shepherd the permit applications through the necessary steps and processes required by Canadian federal and Quebec provincial agencies. The use of a Quebec-based consultant, fluent in French, is expected to help eliminate problems arising from the language barrier and unfamiliarity with Canadian and Quebec permitting requirements. In addition to the original one-time costs to build the weir, there will be a recurring cost of paying a local worker to tend to the integrated fish trap. For an approximate 105-day period, a local worker will need to tend the trap every Monday, Wednesday, and Friday; about 45 days of work per year. A typical visit to the trap site would take about 1 hour for MVC, AVC, and SVC designs and perhaps up to 2 hours for the FTS design. To compensate for travel time, fuel, and work performed by the selected seasonal attendant, a stipend payment by U.S. agencies of approximately $5,000 U.S. dollars will be paid for each season of work.

All costs for the project are estimated in U.S. dollars. Material and labor costs were derived from the R.S. Means Building Construction Cost Data, 63rd Annual Edition. A location factor adjustment for Quebec is reported where materials cost 118% of those estimated here, however, Quebec labor costs are only 81% of what is planned in these estimates. The total construction costs for a Montreal location (which will likely be the source of our contractors) are estimated to be 101.8% of the cost estimates listed in the tables below.

Table 2. Preliminary conceptual cost estimates for the Automated Variable Crest Weir (***AVC***) on Morpion Stream, Quebec in U.S. dollars.

Item	**Notes**	**Quantity**	**Unit Cost**	**Cost**
Temporary cofferdams	Tailwater @ entrance 100' long sheet pile cofferdam 20'deep	2000 ft^2	$25.00	$50,000
Sheet pile cut-off wall		1030 ft^2	$25.00	$25,750
Concrete	Base & Apron	20 yd^3	$600.00	$12,000
Adjustable gate weir		NA	NA	$60,000
Control station	Building	NA	NA	$20,000
Control	Hydraulics and electrical	NA	NA	$20,000
Handrail		100 ft	$40.00	$4,000
Lamprey trap		NA	NA	$5,000
Riprap and gravel bedding		75 yd^3	$30.00	$2,250
Cover grating		200 ft^2	$20.00	$4,000
Miscellaneous	Anchor bolts	1000 Lbs.	$2.00	$2,000
	Cover grating anchors	200 Lbs.	$3.00	$600
	Misc. metal	700 Lbs.	$2.00	$1,400
Silt fence and sediment control		NA	NA	$4,000
Access road improvements		NA	NA	$20,000
Total Direct Costs				**$231,000**
Mobilization/ Demobilization			10%	
Contingencies			15%	
Engineering			15%	
Total Indirect Costs			**40%**	**$92,400**
Total Costs				**$323,400**

Table 3. Preliminary conceptual cost estimates for the Seasonal Variable Crest Weir (***SVC***) on Morpion Stream, Quebec in U.S. dollars.

Item	**Notes**	**Quantity**	**Unit Cost**	**Cost**
Temporary cofferdams	Tailwater @ entrance 100' long sheet pile cofferdam 20' deep	2000 ft^2	\$25.00	\$50,000
Sheet pile cut-off wall		1030 ft^2	\$25.00	\$25,750
Concrete	Base & Apron	20 yd^3	\$600.00	\$12,000
	Walls	40 yd^3	\$600.00	\$24,000
Handrail		100 ft	\$40.00	\$4,000
Lamprey trap		NA	NA	\$5,000
Stop-log lumber		1200 board ft.	\$6.50	\$7,800
Riprap and gravel bedding		75 yd^3	\$30.00	\$2,250
Cover grating		500 ft^2	\$20.00	\$10,000
Miscellaneous	Anchor bolts	1000 Lbs.	\$2.00	\$2,000
	Cover grating anchors	500 Lbs.	\$3.00	\$1,500
	Misc. metal	500 Lbs.	\$2.00	\$1,000
Silt fence and sediment control		NA	NA	\$2,000
Access road improvements		NA	NA	\$20,000
Total Direct Costs				**\$167,300**
Mobilization/ Demobilization			10%	
Contingencies			15%	
Engineering			15%	
Total Indirect Costs			**40%**	**\$66,920**
Total Costs				**\$234,220**

Table 4. Preliminary conceptual cost estimates for the Seasonal Flow-Through Screen Weir (***FTS***) on Morpion Stream, Quebec in U.S. dollars.

Item	**Notes**	**Quantity**	**Unit Cost**	**Cost**
Temporary cofferdams	Tailwater @ entrance 80' long sheet pile cofferdam 15' deep x 2	2400 ft^2	$15.70	$37,680
Aluminum bar racks	50'6" x 10'	505 ft^2	$39.50	$19,948
Bar rack framing	Linear feet plus corners	150 lf	$15.60	$2,340
	Corners	30 each	$6.15	$185
Timber Crib	Base Crib	480 ft^2	$33.50	$16,080
	Tie Backs	8 each	$1,650.00	$13,200
Timber Abutments	Beams and lagging	960 ft^2	$33.50	$32,160
Timber Supports	Timber	500 lf	$6.50	$3,250
Handrail	Timber	100 lf	$17.55	$1,755
Decking	Timber	300 ft^2	$9.70	$2,910
Lamprey trap	Lump sum	NA	NA	$5,000
Riprap and gravel bedding	100 lb average	134 sq yd	$77.00	$10,318
Miscellaneous	Anchor bolts	1000 Lbs.	$2.00	$2,000
	Connector anchors	500 Lbs.	$3.00	$1,500
	Misc. metal	500 Lbs.	$2.00	$1,000
Silt fence and sediment control	Lump sum	NA	NA	$2,000
Access road improvements	Lump sum	NA	NA	$20,000
Total Direct Costs				**$171,326**
Mobilization/ Demobilization			10%	
Contingencies			15%	
Engineering			15%	
Total Indirect Costs			**40%**	**$68,530**
Total Costs				**$239,856**

Table 5. Additional indirect costs in U.S. dollars that are equal for all weir design.

Item	**2000 estimate**	**2005 estimate**	**Projected Cost**
Land Easement Acquisition	$45,000	$55,000	$55,000
Environmental Consultant		$15,000	$15,000
Total			**$70,000**

When adding Table 5 to the estimated construction costs from Tables 2 - 4, the final estimated costs for construction of each weir type would be:

MVC = $378,400 U.S. dollars
AVC = $393,400 U.S. dollars
SVC = $304,220 U.S. dollars
FTS = $309,856 U.S. dollars

Recurring annual costs for operation would be approximately $5,000 U.S. dollars which may increase with time to account for inflation.

3.4 Cofferdam Construction

Temporary cofferdams will be used to allow the construction of any of the four weirs. Water must be temporarily diverted so that materials can be worked on in a non-submergent environment. This will be done by forcing flows into one half of the channel at a time. Water will be channeled against the right bank while working on the left bank and vice versa. No new channel will be dug. The existing channel is adequate to receive all flow through one half of its width temporarily. Banks will be protected with sheet piling or other reinforcement to counter the increased susceptibility to erosion during this period of construction.

4.0 Environmental Impacts

Impoundments and barriers affect the natural flow of a river in respect to its physical, chemical, and biological attributes. These riverine metrics increase or decrease gradually from headwaters to mouth according to the river continuum concept (Vannote et al. 1980). The metrics of the river also vary laterally during the year as the river reaches the extent of its floodplain according to the flood-pulse concept (Junk et al. 1989). When a barrier is placed in a river, longitudinal and lateral metrics are interrupted and shifted, resulting in a serial discontinuity (Ward and Stanford 1983; 1995). All impoundments have some effect on processes such as nutrient and sediment transport, temperature, and species assemblages, but the magnitude of discontinuity and its effective distance in Morpion Stream is relatively small because of its proximity to the confluence with the Pike River. Additionally, the seasonal operation of the proposed weirs means that there will be approximately nine months of the year in which physical, chemical, and biological attributes can return to normal form and function. Discontinuities produced by the weirs are both temporary and reversible.

Any barrier has the potential to affect the local flora and fauna in two ways: 1) preventing movement of species that use the waterway for seasonal or diurnal passage and 2) impounding water in an area that previously flowed freely and at lower stage heights. Because of the weir designs and their seasonal operation, the effects of a sea lamprey weir in Morpion Stream are expected to be minor.

4.1 Species Affected

4.1.1 Fishes

A complete survey of all fish that use Morpion Stream either throughout the year or for migration has not been conducted. However, limited trapping in 2003 in Morpion

Stream and stream inventory surveys (Walrath and Swiney 2001) yielded the list of species in Table 6. Twenty-seven additional species (Table 7) have been reported to occur in the Pike River and therefore have access to Morpion Stream. Of the species trapped in Morpion Stream, the majority are resident species, inhabiting the river throughout the year. Only adult sea lamprey, adult silver lamprey, adult white suckers, and a few cyprinid species are known to use Morpion Stream for a spring spawning migration route. As far as the authors can determine, the use of Morpion Stream by species such as rainbow trout, burbot, walleye, and other migratory species has not been recorded.

Table 6. List of fish species surveyed from Morpion Stream, Quebec

Common English Name		**Scientific Name**
American brook lamprey		*Lampetra appendix*
Black crappie		*Pomoxis nigromaculatus*
Blacknose dace		*Rhinicthys atratulus*
Bluegill		*Lepomis macrochirus*
Bluntnose minnow		*Pimephales notatus*
Brown bullhead	*	*Ameiurus nebulosus*
Central mudminnow		*Umbra limi*
Common shiner	*	*Luxilus cornutus*
Creek chub	*	*Semotilus atromaculatus*
Eastern silvery minnow	*	*Hybognathus regius*
Emerald shiner		*Notropis atherinoides*
Fallfish	*	*Semotilus corporalis*
Fantail darter		*Etheostoma flabellare*
Fathead Minnow	*	*Pimephales promelas*
Golden shiner	*	*Notemigonus crysoleucas*
Largemouth bass		*Micropterus salmoides*
Logperch	*	*Percina caprodes*
Longnose dace		*Rhinicthys cataractae*
Pumpkinseed	*	*Lepomis gibbosus*
Rock bass	*	*Ambloplites rupestris*
Sea lamprey	*	*Petromyzon marinus*
Silver lamprey		*Ichthyomyzon unicuspis*
Smallmouth bass	*	*Micropterus dolomieui*
Stonecat	*	*Noturus flavus*
Tessellated darter	*	*Etheostoma olmstedi*
White perch	*	*Morone Americana*
White sucker	*	*Catostomus commersoni*
Yellow perch	*	*Perca flavescens*

* = trapped in Morpion Stream in 2003 during spring lamprey trapping

Table 7. List of Pike River species not previously reported in Morpion Stream, Quebec

Common English Name	**Scientific Name**
Alewife	*Alosa pseudoharengus*
American eel	*Anguilla anguilla*
Banded killifish	*Fundulus diaphanous*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Burbot	*Lota lota*
Carp	*Cyprinus carpio*
Cisco	*Coregonus artedi*
Freshwater drum	*Aplodinotus grunniens*
Greater redhorse	*Moxostoma valenciennesi*
Johnny darter	*Etheostoma nigrum*
Lake whitefish	*Coregonus clupeaformis*
Mimic shiner	*Notropis volucellus*
Muskellunge	*Esox masquinongy*
Northern pike	*Esox lucius*
Quillback	*Carpiodes cyprinus*
Rainbow trout	*Oncorhynchus mykiss*
Rainbow smelt	*Osmerus mordax*
Redfin pickerel	*Esox americanus*
Sand shiner	*Notropis stramineus*
Shorthead redhorse	*Moxostoma macrolepidotum*
Silver redhorse	*Moxostoma anisurum*
Spotfin shiner	*Cyprinella spiloptera*
Spottail shiner	*Notropis hudsonius*
Threespine stickleback	*Gasterosteus aculeatus*
Walleye	*Sander vitreus*
Yellow bullhead	*Ameiurus natalis*

The effects of low-head, fixed-crest, permanent lamprey barriers on fish in rivers have been widely studied and repeatedly show significant, yet limited effects on the fish community structure (Dodd et al. 2003; Hayes et al. 2003; Klingler et al. 2003; Lavis et al. 2003; Porto et al. 1999). Dodd et al. (2003) studied 24 pairs of streams and concluded that a mean of 2.4 species was lost from stream sections upstream of barriers. Twenty-two of those barriers were permanent fixed-crest barriers and the other two AVC designs did not mention fish passage mitigation. All seasonally operated weirs with traps for fish passage are expected to have less of an impact than the fixed crest designs evaluated by Dodd et al. (2003).

Migratory spawners would be most affected by a barrier because a stage of their reproductive process is interrupted. Barriers have less of an effect on resident populations of the stream who may migrate, but reside and spawn above the barrier. This is true for fixed-crest permanent barriers. The weirs we propose to construct include a fish trap, and are only proposed for operation during the spring. It is a temporary structure that allows free fish passage for nine months out of the year and provides a mechanism for catching and transporting fish above the weir during the period of operation. Every known species from Morpion Stream that would potentially need to be transported above the weir can be accommodated by the fish trap engineered for these weir designs.

4.1.2 Other Fauna

There are mussel species in the Lake Champlain Basin that depend on specific fish species to serve as hosts to their glochidia. If the host fish were prevented from reaching mussel beds in the upper portions of Morpion Stream, then there would be reason for concern about their persistence. However, with the fish passage design used for any of these weirs, the only species that would be completely prevented from migrating up Morpion Stream are fish that are too large to enter the fish trap such as sturgeon, large salmonids, or large walleye. Because none of these species have ever been documented in Morpion Stream, the mussel community should have access to its necessary compliment of resident host species and migratory species passed over the weir.

There are numerous avian, herpetile, mollusk, insect, and mammal species that inhabit Morpion Stream and its riparian areas. Among all of these species, there are no foreseeable instances where organisms would be caused substantial stress or experience unavoidable adverse habitat conditions as a result of this relatively small and seasonal impoundment of water. Adverse effects would only result if a species required access to the upper portion of Morpion Stream during the months of weir operation and was unable to be trapped and lifted over the weir.

4.1.3 Flora

The section of Morpion Stream that would be impounded contains very little aquatic vegetation with the exception of microalgae. The banks of the stream are relatively steep and exhibit high clay content. This results in mostly mud-bank riparian areas, but with some vegetation. The impoundment of the stream would cause the submersion of some riparian bank vegetation. The impounded water may allow for some new aquatic vegetation to develop in the still waters. Overall, changes in floral richness and density will not be substantial because of the relatively small impoundment area, volume, and seasonal operation of the proposed weirs.

5.0 Operational Duration

For a lamprey weir to be effective it must prevent the vast majority of migrating lamprey from gaining access to the spawning grounds above the weir. This requires that the weir be in place throughout the potential migratory season of sea lamprey. In the Lake Champlain Basin, it has been found that lamprey migration commences soon after the ice recedes from the rivers. The heaviest migration period occurs from mid-April through mid-May. Migration continues in some rivers throughout the month of June. On Morpion Stream, we propose to install a weir apparatus and begin operation of the trap each year on or around (depending upon recent local weather) April 1st to insure the trapping of early migrant lampreys. Trapping would cease based on an evaluation of catches within the trap beginning on May 15th. After a period of 14 consecutive days in which no lamprey were captured, the weir would be lowered/removed.

6.0 Expected Effects of a Weir on the Lamprey Population of Lake Champlain

The most recent survey of the Pike River and Morpion Stream provide the only means to directly estimate how many lampreys could be eliminated by the installation of a weir in Morpion Stream. The best-case scenario would be the prevention of all sea lamprey spawning in Morpion Stream and the removal of all migrating adults, thus preventing them from finding other locations in the Pike River or elsewhere to spawn. This could result in the reduction of over 3,000 parasitic lampreys estimated to be produced from the Pike River watershed annually. This estimate is based on densities of transformed, parasitic lamprey that were sampled in both the Pike River and Morpion Stream. Their parasitic population was estimated using a quantitative lamprey assessment protocol (Slade et al. 2003 and Appendix A).

A worst-case scenario (assuming the weir is effective in preventing migration), would be that significant numbers of adults encounter the weir and are not trapped, thus allowing them to find other spawning grounds. Additionally, if some lamprey were to pass the weir during a high-water event, the potential for compensatory recruitment may occur (Jones et al. 2003). Under this scenario, the proportion of individuals produced from a pair of spawning lamprey that recruit to the juvenile stage increases substantially as the number of spawning pairs decreases. This means that the relationship between number of recruited juveniles and spawning pairs is not linear. The relationship would conceptually resemble a $y=log(x)+b$ type response where x is the number of spawning pairs, b is a number of offspring produced, and y is number of juveniles recruited. Although this phenomenon is mostly speculative and has not been clearly demonstrated, the fecundity of sea lamprey is high enough (60,000+ eggs per female) that even a solitary pair could produce a sizable number of offspring.

The expected result of weir construction is somewhere between these two scenarios with experience from the Great Lakes sea lamprey control program suggesting it would be closer to the best-case scenario (Lavis et al. 2003). Larval length data (Figure 1) indicate that the majority of spawning in the Pike River watershed occurs within Morpion Stream, with the Pike River serving primarily as a rearing ground for older larvae. Therefore, installing this weir in Morpion Stream, resulting in the removal of 29 km of active spawning and rearing habitat, will substantially reduce the number of reared larvae and resulting parasites produced from the Pike River watershed.

Although a weir is a solution to reducing the number of lamprey produced from the Pike River watershed, its effects will not be realized for years to come. Because of the lamprey life cycle, there are four or more year-classes of larvae in the stream at any given time. Sea lamprey hatched in the summer of a given year will not become parasites for at least four years. For example, if a weir prevents upstream migration for the first time in 2006, parasites will continue to be produced until 2009 (offspring from 2005 matings). Our only measure of parasitic and adult lamprey density in Lake Champlain is obtained from surveys of host species to determine the frequency of lamprey wounds. After a parasitic lamprey exits its natal stream, it spends 12-18 months parasitizing a host. Based on that time-scale, the effects of a weir that prevents migration for the first time in 2006 would not contribute to a reduction in wounding rates among Lake Champlain host species until 2011.

7.0 Project Conformity to Recommended Guidelines from Quebec

A letter dated 17 April 2003, from Monsieur Gérard Cusson, Acting Regional Director of the Ministere de l'environnement Québec, states that Quebec Provincial "regulations currently forbid the use of lampricides in watercourses." This precipitated the development of our alternatives to lampricide usage contained within this report. The following mandatory or advisable criteria were also specifically identified by Monsieur Cusson that need to be satisfied in order to submit an official application for construction of any proposed weir. The following text will address each of those points and the action needed or completed to address each one.

7.1 Authorization from land owners

Before the official application for construction is submitted to the appropriate Québec authorities, written permission must be obtained from the Notre-Dame-de-Stanbridge residents who own land on Morpion Stream at the site of the weir and along the section of Morpion Stream that will be impounded. These permissions have not yet been obtained. Once this report is approved by the Lake Champlain Basin Program, the report will be provided (in English and French) to landowners whose permission is sought. Written letters of permission will then be attached to the official application for construction. This process will be facilitated by hiring a private environmental consultant from Québec.

7.2 Zoning and Existing Legal Regulations

Several provincial and local statutes require authorization from authorities signifying that the intended use of the land (weir construction and operation) is in accordance with local zoning regulations and statutes. A certified letter has already been obtained from the regional county municipality of Brome-Missisquoi granting its permission for the project. USFWS is in contact with the municipality of Notre-Dame-de-Stanbridge, who has agreed to review this report and contingently grant permission from the municipality thereafter.

7.3 Information about the site location and description.

Section 2 of this report describes the site and local conditions where the weir is proposed for construction. Specific data used for designing the weir are included in Appendices B and C of this report.

7.4 Inform Canadian Department of Fisheries and Oceans (DFO) of Project and Plans

This report will be submitted to the DFO prior to official application to receive guidance from that agency on steps that are necessary to help ensure a successful application. All correspondence regarding this project will be copied to Monsieur Pedro Nilo of the DFO in Montreal.

7.5 Complete study on the impacts on wildlife and the environment, including mitigation measures

Section 4 addresses the expected effects on the flora and fauna resulting from weir construction. As described earlier, the limited size, seasonal operation, ability to be removed, and the trapping operation used to mitigate fish passage demonstrate the weirs' low-impact on non-target species and our commitment to mitigating their potential effects. Data will be collected each year at the fish trap recording species, their numbers, and any mortality. These data will be provided to all proper Canadian and Quebec authorities and used as necessary to improve mitigation procedures.

7.6 Develop indicators that would allow the shortest duration of operation needed

The most direct indicator of operational duration is the presence of lampreys in the trap. As described in section 5.0, the end of the spawning season for lamprey is determined by direct observation. Identifying the commencement of the spawning season is more difficult. If after consecutive years of trapping at the weir, we find that April 1st is earlier than needed to begin trapping, then we will adjust our operational duration accordingly. Additionally, we are working on developing an empirical model that will help predict the onset of migration based on temperature and date.

7.7 Plan barrier structures so that they can be removed after lamprey have finished migrating

As described in section 3.2.2 to 3.2.5, the recommended weir designs allow for the removal of flow-impeding structures when they are not in use. The weirs can be either installed or removed from their anchoring framework or lowered in the case of the MVC and AVC, leaving no impounded areas or impedance to free passage once removed.

7.8 Make the constructed barrier, including its bank-securing framework, as easy to remove as possible for when operation of the barrier is no longer needed.

The portion of the weir frameworks that would be left in place after the weir components are removed consists of steel sheet pilings and base apron strips (either concrete or timber crib). In the future, if these weirs were to be decommissioned, the structures could be dug from the ground and pulled out with heavy machinery. To accommodate a temporary and seasonally operated weir however, these framework pieces need to be strong to provide sufficient support.

7.9 Minimize impoundment so that agricultural drainage is not affected

Because a 1-meter crest height is necessary to obtain satisfactory lamprey control effectiveness, high flows in the spring would likely create varying degrees of flooding. Exact flood conditions can be predicted under varying scenarios by looking at Figure C-31 in Appendix C and comparing it to all the bank elevation models (Figures C3-C28). Exact drainage of fields cannot be predicted with existing data, but the height of the impoundment during high flows will have a greater inundating effect on surrounding lands than was seen in the past. The FTS design does not rely on crest heights and would have little if any impounding effects. Therefore, the FTS design would be the most hydrologically benign of the barriers proposed within this report. Surrounding lands would not flood because of an FTS structure, but may experience normal flooding under high water conditions.

7.10 Ensure that operation of the dam will not create stream bed or bank erosion

Stream bed and bank erosion results from "sediment-hungry," low turbidity water that is released from large reservoirs or from fast-flowing waters. It scours banks and beds because it has a greater ability to accommodate sediment transport. The MVC, AVC, and SVC weir designs at Morpion Stream would create very shallow impoundments. The water that spills over their 1-meter crests has little hydraulic force and little potential for increased sediment transport. With sheet pilings along the banks at the weir site and no constriction of flow, there is no cause for concern about either bank or stream bed erosion based on the three proposed variable crest designs. Upon termination of seasonal operation of the MVC and AVC designs, the crest will be lowered incrementally to simulate the rate of stream stage lowering after a high-water event. This same incremental lowering of stream stage at the end of the season would be done with the SVC design by removing stop logs over a period of several days. The specific location of released flows can be directed by selecting which stop logs are removed. This would allow increased-velocity water to be focused within the channel and away from banks. The FTS design does not create an impoundment and would result in even fewer effects on channel degradation. With no impoundment, its removal at the end of the season will not result in any change in stream stage. All four designs use various forms of bank reinforcement to prevent bank erosion immediately above and below the instream structures. Any erosional effects created by the presence and operation of the weir will be promptly mitigated through reinforced and stabilized bank improvements to maintain bank and channel integrity.

7.11 Allow for free movement of aquatic species upstream and downstream

Free movement is facilitated by two different means under the three variable crest construction plans. First, the simple removal of the temporary weir for approximately nine months of the year allows for free movement of all species, the same as if there were no weir. Second when the weirs are in place, a two-stage fish trap is used to pass fish and other collected fauna above the weir. Downstream movement is not impaired as organisms can safely pass over the low-head crest of the weirs. The FTS design is similar in that it is only in place for about three months and uses a trap to pass larger fish upstream. However, the mesh size of the screen also allows smaller fish to pass freely upstream and downstream, yet makes passage of larger fish in the downstream direction more difficult.

7.12 Ensure a regular presence in the area

One or more individuals will be contracted to tend the trap and maintain the weir on a 2-3 day cycle during operation. The individuals will be required to report to the U.S. Fish and Wildlife Service weekly, providing catch and weir status data, thereby ensuring a regular presence. U.S. Fish and Wildlife Service personnel will be available to perform maintenance checks or repairs at the weir and trap as needed to keep the apparatus functioning properly. U.S. Fish and Wildlife Service personnel will also be responsible for the installation and removal of the weir each year.

7.13 Hire local workers for construction

The site and weir design will be engineered by professional hydrologic engineers of the U.S. Fish and Wildlife Service. Once drawings and plans are in place, local Québec construction contractors will be asked to bid on the job for the physical construction of the weir.

8.0 Summary

- A site on Morpion Stream has been identified that would allow for the effective construction of a lamprey weir
- Four weir designs have been proposed that each feature seasonal operation, a removable design, and incorporate a trap used to mitigate fish passage.
- Weirs would operate for approximately 3 months each year at which time all impounding structures would be removed
- The impact on the biological, chemical, and physical attributes of Morpion Stream would be very small because of the short duration of operation, the relatively small size of the weirs, and the steps taken to mitigate fish passage.
- Implementation of a weir has the potential to substantially reduce the contribution of the Pike River watershed as one of the current high-producers of sea lamprey.

9.0 Recommendations

The Lake Champlain Fish and Wildlife Management Cooperative recommends that:

- U.S. Fish and Wildlife Service work in close coordination with government and private interests in Quebec to insure that a mutually acceptable design and construction plan for a sea lamprey barrier on Morpion Stream be developed, installed, and operated.
- An application be submitted, in accordance with this report, to the proper authorities in Quebec requesting permission for the construction of a weir.
- All action relating to the ultimate construction of this weir be taken swiftly to prevent as many generations of new lamprey as possible from being spawned in Morpion Stream.

Acknowledgements

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8.0 Sommaire

- Un site dans le ruisseau aux Morpions qui conviendrait à la construction d'un barrage de lamproie a été identifié;
- Quatre concepts de barrage ont été proposés avec une opération saisonnière, une conception démontable et des pièges pour capturer la lamproie marine et pour déplacer d'autres espèces de poissons au-dessus du barrage;
- Les barrages fonctionneraient pendant environ trois mois par an. Tous les composants de retenue de l'eau seront enlevés annuellement après la période d'opération;
- Les impacts sur l'environnement du ruisseau aux Morpions seront réduits au minimum en raison de la courte période d'opération, la petite taille des barrages, et les mesures prises pour permettre le passage des poissons;
- La construction d'un barrage dans le ruisseau aux Morpions, l'un des endroits qui produit le plus de lamproie marine, possède le potentiel pour réduire sensiblement la contribution de la lamproie marine dans le bassin versant de rivière aux Brochets du lac Champlain.

9.0 Recommandations

La Coopérative de Gestion de Poissons et de Faune de lac Champlain recommande que:

- Le promoteur travaille en étroite coordination avec le gouvernement du Québec et des intervenants du milieu pour s'assurer que le concept et le plan de construction pour un barrage de lamproie marine sur le ruisseau aux Morpions soient mutuellement acceptables afin de le développer, l'installer et l'opérer;
- Une application soit soumise selon ce rapport aux autorités compétentes du Québec pour demander la permission afin de construire un barrage;
- Toutes les mesures concernant la construction de ce barrage soient prises rapidement pour empêcher la future reproduction de lamproie dans le ruisseau aux Morpions.

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APPENDIX A:

Equations for the calculation of Sea Lamprey stream population estimates

Estimated total stream abundance ($\hat{R}$) was estimated from:

(1) $$\hat{R} = A\left[\overline{D}_I \hat{p}_I + \overline{D}_{II} \hat{p}_{II}\right]$$

where A is the total area of the stream, $\hat{p}_i$ is the estimated proportion of type I or II habitat, and $\overline{D}_i$ is the estimated mean larval density in Type I or II habitat.

Confidence Intervals

Confidence intervals around mean larval sea lamprey population estimates were calculated using the following formulae:

(2) $$\hat{R} \pm t_{\alpha(2),\nu} \sqrt{\frac{\mathrm{var}(\hat{R})}{n_I + n_{II}}}$$

where $\hat{R}$ comes from equation 1 or 2 above, α = 0.20, $\nu = n_I + n_{II} - 1$, n_i is number of plots electrofished in Type I or II habitats, and

(3) $$\mathrm{var}(\hat{R}) = A^2\left[\sum_{i=I}^{II}\left(\overline{D}_i^2\ \mathrm{var}(p_i) + \hat{p}_i^2\ \mathrm{var}(D_i)\right)\right]$$

where:

(4) $$\mathrm{var}(p_i) = \frac{\hat{p}_i \hat{q}_i}{n_i - 1}$$

$\hat{q}_i = 1 - \hat{p}_i$ and n_i is the number of Type I or II habitats that were measured, and

(5) $$\mathrm{var}(D_i) = \frac{\sum_{j=1}^{n}\left(D_j - \overline{D}_i\right)^2}{n_i - 1}$$

where D_j are per plot densities, $\overline{D}_i$ is mean plot density, and n_i is number of plots electrofished in Type I or II habitats.

APPENDIX B: Hydrology

Gages and Drainage Area Delineation and Determination

The proposed barrier/trap site is at the confluence of the Pike River-Morpion Stream approximately ½ kilometer downstream from the dam at Notre-Dame-de-Stanbridge on the Pike River (45^o 10' Longitude 73^o 02'). A water stage-discharge gauging station has recently been established by the Ministere de L'Environnement, Centre d'expertise hydrique, Quebec on the Pike River immediately upstream from the covered bridge at Notre-Dame-de-Stanbridge. The gage, 030424 - Aux Brochets Notre-Dame-de-Stanbridge (pont couvert) has an upstream drainage area documented to be 586.09 square kilometers (226.29 sq. mi.). Scaled maps were digitized and drainage area delineated for both the Pike River and sub-basin for the Morpion Stream. The Morpion Stream sub-basin was estimated to be 113.5 square kilometers (43.8 sq. mi.) The Morpion Stream sub-basin is the northern most and predominantly drains agricultural lands of the St. Lawrence River Valley. The general relief of the sub-basin is flatter than the upper portion and headwaters of the Pike River which originate in Northern Vermont.

Flow Data Comparison with USGS Gauging Stations in the Lake Champlain Basin

The US Geological Survey gauging station database was queried to locate representative or comparative sites on streams draining into Lake Champlain with roughly similar drainage characteristics to estimate the average annual flow in the Pike River and Morpion Stream and the percent of time the river flow is equaled or exceeded during the spring months. For fish passage structures in the northeast, a starting point is to estimate the average annual discharge by multiplying 2 times the drainage area (raised to the 1 power). This equates to an average annual discharge in the Pike River of about 12.8 cubic meters per second (450 cfs) and in the Morpion Stream 2.6 m3/s (90 cfs). Table B-1 gives gauging station data with the ratio of average annual discharge to drainage area computed. Using a ratio of 2 represents the upper bound of the data.

Table B-1 Showing Comparison of River Discharge to Drainage Area			
Gage	Average Annual Discharge (cfs)	Drainage Area (square miles)	Ratio
Mettawee River at Pawlet	119	70.2	1.7
Otter Creek at Middlebury	1005	628	1.6
Lewis Creek at North Ferrisburg	105	77.2	1.4
Great Chazy at Perry Mills	280	243	1.15
Larger Basins			
Missisquoi River at Swanton	1631	850	1.92
Winooski River at Essex Junction	1744	1044	1.67

Based on daily streamflow data for the 4 smaller drainage area gages, monthly stream flow frequency curves were obtained from the USGS gage data. The monthly curves were transposed to the Pike River and Morpion Stream by ratio of the drainage area and averaged in order to develop a representative monthly curve for each of the months from March through June.

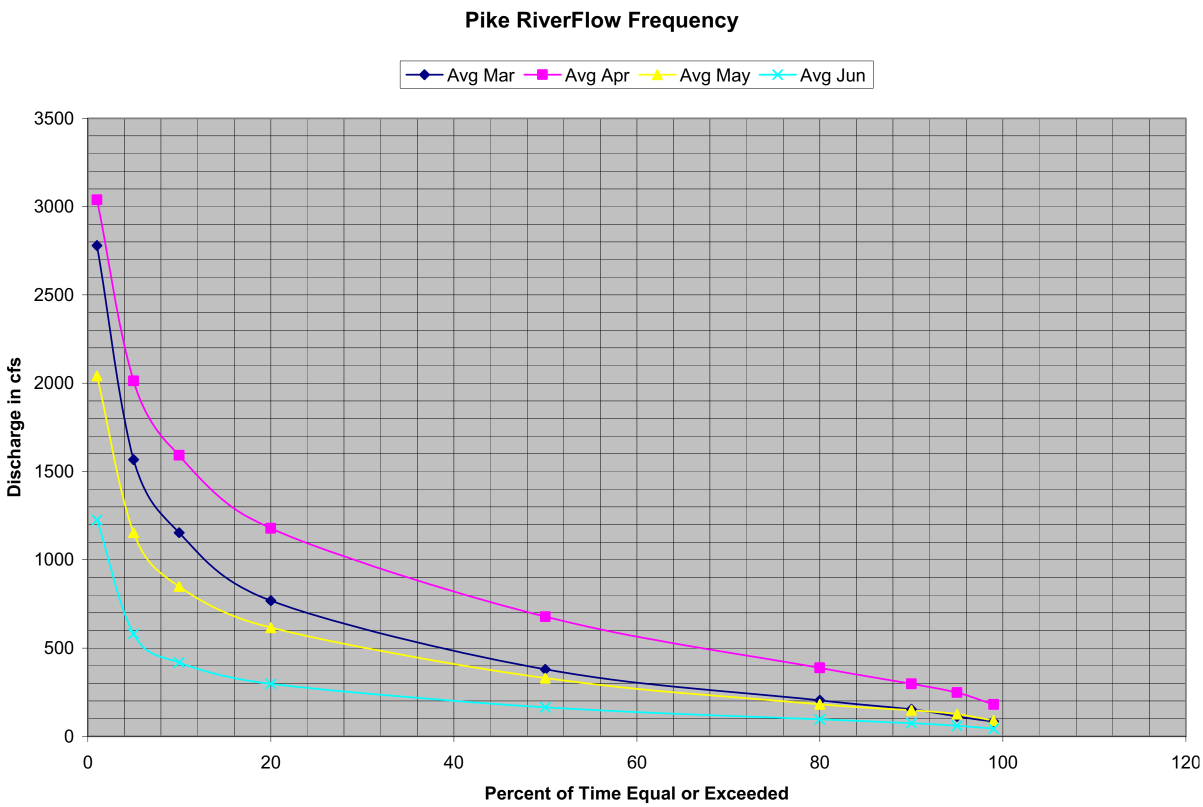


Figure B-1: Showing the Pike River Discharge Frequency Curves

The median April/May flow discharge would be equal to or exceeded 50 percent of the time and graphically located between the 2 curves at a discharge of 500 cfs (14.2 m^3/s) for the Pike River.

Using the data from the 4 smaller basins, an average April flow of 841 cfs (23.8 m^3/s) and an average May flow of 441 cfs (12.5 m^3/s) were computed which equates to an overall average April/May flow equal to 641 cfs (18.2 m^3/s) for the Pike River.

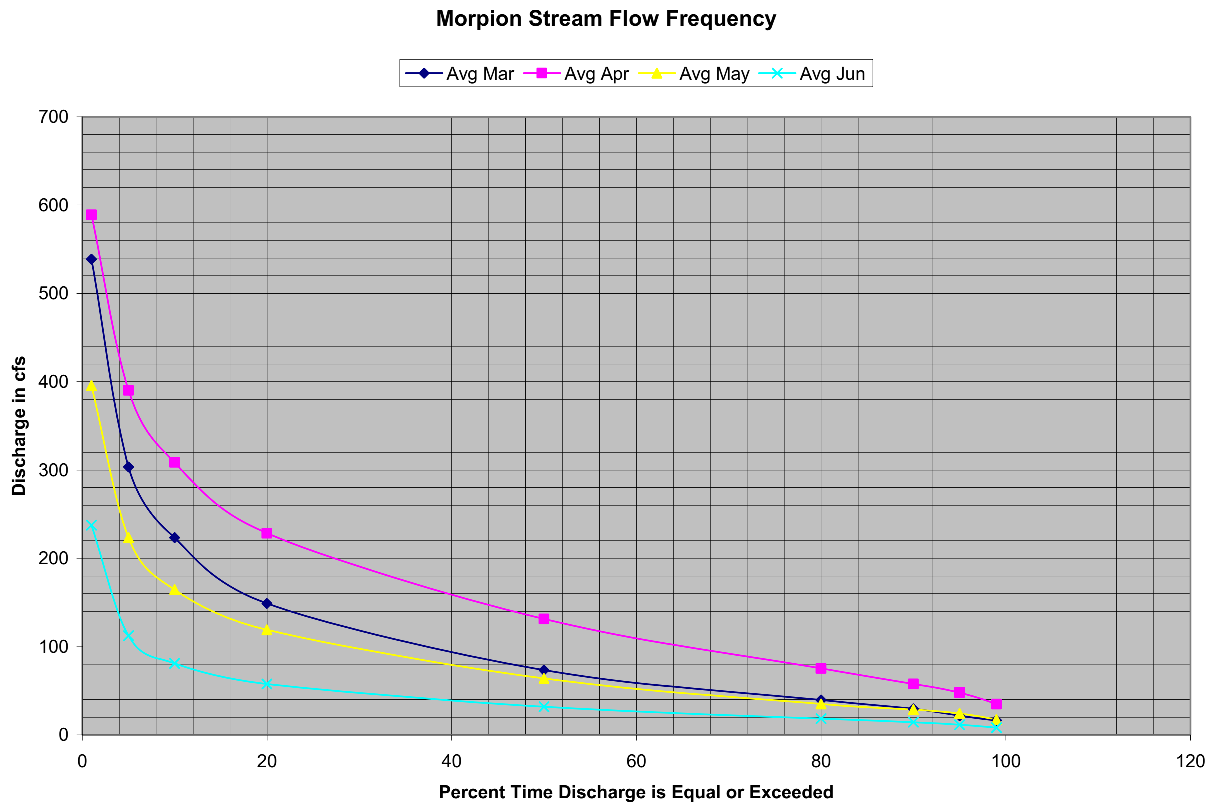


Figure B-2: Showing the Morpion Stream Monthly Discharge Frequency Curve

The median April/May flow discharge would be equal to or exceeded 50 percent of the time and graphically located between the 2 curves at a discharge of 100 cfs (2.8 m^3/s) for the Morpion Stream.

Using the data from the 4 smaller basins, an average April flow of 163 cfs (4.6 m^3/s) and an average May flow of 86 cfs (2.4 m^3/s) were computed which equates to an overall average April/May flow equal to 125 cfs (3.5 m^3/s) for the Morpion Stream.

Flood Frequency Study for the Pike River and Morpion Stream

In order to determine the flood frequencies for the Pike River and the Morpion Stream sub-basin, a search of USGS database was made to locate gauging stations having long-term statistical flow records. The following table was developed to compare gauging station data for purposes of transposing data to the Pike River and Morpion Stream.

Table B-2: U.S. Geologic Survey Gage Name	Gage Number	Drainage Area (square miles)	Years of Record
Great Chazy River at Perry Mills	04271500	243	57
Saranac River at Plattsburg	04273500	608	60
Bouquet River at Willsboro	04276500	270	63
Otter Creek at Middlebury	04282500	628	87
Mettawee River at Pawlet	04280350	70	19
Lewis Creek at North Ferrisburg	04282780	77.2	13
Lamoille River at Johnson	04292000	310	78
Lamoille River at East Georgia	04292500	686	74
Missisquoi River near East Berkshire	04293500	479	83
Winooski River at Montpelier	04286000	397	87
Winooski River at Essex Junction	04290500	1044	75
Poultney River Below Fair Haven	04280000	187	75

Gumbel Extreme Value Distribution Method Flood Probability Analysis

The gages having long term periods of record and drainage areas greater than 150 square miles were used in the flood frequency analysis. Yearly flood peaks were retrieved and sorted to develop Gumbel frequency distributions at each of the gages on Table B-3. Flow values were obtained for the 1.005-year, 2-year, 5-year, and 10-year frequencies. The data were transposed to the Pike River by a direct ratio of the drainage areas. All discharges are in cubic feet per second (cfs).

Table B-3 Gumbel Extreme Value Analysis Summary of Estimated Peak Discharge Frequencies by River						Pike River transposition for 226 sq mi DA			
	1-yr	2-yr	5-yr	10-yr	DA	1-yr	2-yr	5-yr	10-yr
Poultney	474	4,314	5,870	7,635	187	573	5,214	7,094	9,227
Otter	1700	4,370	5,758	6,641	628	612	1,573	2,072	2,390
Winooski-Mtp	1800	6,600	10,377	11,536	379	1,073	3,936	6,188	6,879
Lamoille-J	2700	7,325	9,099	11,400	310	1,968	5,340	6,634	8,311
Lamoille-Ega	7300	13,000	16,714	19,627	686	2,405	4,283	5,506	6,466
Missisquoi	4900	10,600	13,237	16,100	479	2,312	5,001	6,246	7,596
Great Chazy	2100	3,750	4,821	5,813	243	1,953	3,488	4,484	5,406
Saranac	2400	5,655	7,663	9,211	608	892	2,102	2,848	3,424
Boquet	1200	4,600	7,029	8,833	270	1,004	3,850	5,883	7,394
Average						1,421	3,865	5,217	6,344

Log Pearson Type III Distribution Flood Probability Analysis

Using the USGS program, a Log Pearson Type-III Flood Frequency Analysis was completed for the same set of gauging stations and the results are supplied in Table B-4. The data were transposed by ratio of drainage areas

Table B-4 Log Pearson Type III						Pike River			
	1.005-yr	2-yr	5-yr	10-yr	DA	1.005-yr	2-yr	5-yr	10-yr
Poultney	474	4,314	5,870	7,635	187	573	5,214	7,094	9,227
Otter	1959	4,276	5,857	6,991	628	705	1,539	2,108	2,516
Winooski-Mtp	4621	9,483	12,210	13,990	379	2,756	5,655	7,281	8,342
Lamoille-J	2700	7,325	9,099	11,400	310	1,968	5,340	6,634	8,311
Lamoille-Ega	7300	13,000	16,714	19,627	686	2,405	4,283	5,506	6,466
Missisquoi	4900	10,600	13,237	16,100	479	2,312	5,001	6,246	7,596
Great Chazy	2100	3,750	4,821	5,813	243	1,953	3,488	4,484	5,406
Saranac	2400	5,655	7,663	9,211	608	892	2,102	2,848	3,424
Boquet	1200	4,600	7,029	8,833	270	1,004	3,850	5,883	7,394
Average						1,619	4,052	5,343	6,520

Regionalized Distribution from Regression Analysis

Another method to estimate flood frequencies is by regional analysis. The USGS has developed full regression equations based of flood frequency data from gauging stations in Vermont and New York. New York State is divided into a number of sub-regions based on hydrologic factors. The 2 sub-regions closest to the Pike River Drainage were used to estimate flood frequencies in the following table.

Table B-5 Regionalized Flood Frequencies	2-year	5-year	10-year
VT Reg. Analysis	3040	3684	4136
NY Reg. Analysis (Reg 2)	4093	5677	6759
NY Reg. Analysis (Reg 2 DA only)	4285	5896	6986
NY Reg. Analysis (Reg 1)	9151	13724	17012
NY Reg. Analysis (Reg 1 DA only)	4668	6472	7777

TR55 Flood Frequency Program

The final method used to check the frequency analysis was the TR55 Program. Time of concentration of 8.3 hours was estimated based on the longest course of the water through the Pike River drainage. Run-off curve numbers in the range from 60 to 70 would be considered representative of the drainage which has minimal development.

Table B-6 TR55 Flood Estimate	1-year	2-year	5-year	10-year
RCN 60	541	1093	3058	4668
RCN 65	1206	2051	4919	7013
RCN 70	2236	3506	7313	9912

Hydrologic Data Summary

The average April/May discharge for the Pike River was estimated to be 641 cfs (18.2 m^3/s). This would equate by ratio of drainage areas to an average discharge of 125 cfs (3.5 m^3/s) for the Morpion Stream. The best estimates for the 1-, 2-, 5-, and 10-year flood frequency discharges are 1620 cfs (45.9 m^3/s) , 4050 cfs (114.7 m^3/s), 5360 cfs (159.4 m^3/s), and 6780 cfs (192.0m^3/s), respectively.

Using the Log Pearson Type III analysis as the minimum the following table shows the values selected for flood frequencies for the Pike River.

Table B-7: Method Comparison	1-year	2-year	5-year	10-year
VT Regional		3040	3684	4136
Flow Freq Gamma Distribution	1421	3865	5217	6344
Log Pearson Type III	1619	4052	5343	6520
NY Regional		4093	5677	6759
TR55 RCN 65	1206	2051	4919	7013
TR55 RCN 70	2236	3506	7313	9912
Average	1621	3435	5359	6781
Selected Discharges	1620	4050	5360	6780

APPENDIX C: Hydraulic Analysis

Water Surface Profile Model Design

Water surface profile models for both the Pike River and Morpion stream were developed using the Hydrologic Engineering Center, River Analysis System (HECRAS) computer program. The program uses cross section data and computes water surface elevations based on balancing the energy equation from one section to the next upstream in a standard step method. Since the proposed location of the lamprey barrier is such a short distance upstream from the confluence of the Pike River, it was expected that the backwater from the Pike River would influence the tailwater for any barrier in the Morpion Stream. Thus, the Pike River was modeled first to determine the starting conditions at the confluence with the Morpion Stream. Calibration measurements were made both upstream and downstream from the confluence on the Pike River and upstream in the Morpion Stream to verify the influence of the Pike River.

Pike River Model Input Data

A total of 9 cross sections were surveyed in the 2-mile reach of the Pike River from the Notre-Dame-de-Stanbridge dam downstream to the covered bridge. Figure C-3 gives the cross section location map for the sections which are labeled by distance upstream from the downstream most cross section. Cross sections are plotted on Figures C-4 through C-12 from left to right looking downstream. Channel distances between cross sections for the main channel and over-bank areas were measured from the topographic map of the survey. A table of reach lengths and Manning's roughness values is included in Appendix C.

A gauging station, No. 030424, Aux Brochets was recently established by Ministere de L'Environnement, Centre d'expertise Hydrique, Quebec on the Pike River immediately upstream from the covered bridge. A rating curve was provided through consultation with agency staff.

There is some discrepancy between elevations provided in the rating curve and the measured elevations from the survey which used the datum at the brass cap on the bridge. The rating curve starts at a zero streambed elevation 50 (assumed meters), whereas the elevation provided for the brass cap which is on the upstream bridge over the Morpion Stream is 43.9 meters. The rating curves for the Pike River and Morpion Stream are provided as Figures C-14A and C-14B in Appendix C. The rating curve was used as a starting point for calibrating the model and verifying roughness values. Main channel roughness values were expected to be in the range from 0.045 to 0.025 based on photographic records provided in Chow's Handbook of Hydraulics.

Morpion Stream Model Input Data

The HECRAS mathematical model for the Morpion Stream included an additional 14 cross sections that were surveyed from the confluence of the Morpion Stream at an even spacing of about 100 feet (30 meters) between cross sections. Figures C-15 through C-28 in Appendix C are plots of cross sections looking downstream. Where needed, individual data points were interpolated along the cross section orientation perpendicular to the flow.

Model Calibration

Multiple initial attempts were first made to calibrate the model of the Pike River to the rating curve developed for the gauging station located at the downstream end of the study reach. Using a starting elevation of 121.0 feet for zero flow at the gage, the rating curve extended to a maximum elevation of 127.5 feet at a discharge of 14,000 cfs. Starting at a critical water surface elevation, this rating curve could not be duplicated mathematically. The problem is that the datum for the Ministry is at Elevation 50 which would technically be a number of meters higher than the bridge deck over the Morpion stream which has the survey gage bench mark at Elevation 43.9 meters. Thus, the curve could be used as a general check on decreasing roughness with increasing stage.

There were a number of points along the reach where water surface elevations could be measured. However, the most accessible locations that would tie in both ends of the Pike River and the Morpion Stream were at the Covered Bridge and Upstream Dam on the Pike River, and at the Bridge over the Morpion Stream. The following table was developed from the independent measurements taken on 4 different days.

Water Surface Elevation Measurements for Calibration of Pike River and Morpion Stream HECRAS Model

Number	1	2	3	4
Date	3/29/04	3/31/04	4/09/04	4/15/04
Stage at U/S dam	8.92	8.58	7.75	8.30
Crest (local datum)	6.67	6.67	6.67	6.67
Head	2.25	1.91	1.08	1.63
Discharge over Main Weir	1681	1315	559	1036
Discharge over left overflow	72	45	1	26
Total Discharge at U/S Weir	1752	1359	560	1062
At Morpion Bridge				
Brass Cap El.	144.04	144.04	144.04	144.04
Distance measured to WS	11.31	12.02	13.66	12.44
Water Surface Elevation	132.73	132.02	130.38	131.6
Est. Flow in Morpion Stream	56	159	40	280
Flow at Covered Bridge D/S				
Elevation of Pin or Rock	136.03	136.03	136.03	136.03
Measured distance to Water Surface	9.83	10.58	11.89	10.9
Water Surface Elevation	126.2	125.45	124.14	125.13
Flow at Quebec Gage				
Gauging Station Flow (m3/s)	51.2	43	17	38
Flow at Gage in cubic feet per second (cfs)	1808	1518	600	1342

The Pike River has an average slope in the reach downstream from the dam at Notre-dame-de Stanbridge of 0.0009 millimeters/meter. Using that slope and the calibration data the roughness values between 0.045 and 0.025 matched the observed water surface elevations and rating curve with adjustments for reduction in roughness at higher discharges. A sensitivity analysis was done using the 2 downstream most sections to determine which Manning's roughness to use overall or whether an adjustment would be needed for increasing discharge. The channel bottom for the Pike River is fairly rough with cobbles and boulders that would merit use of a roughness value of 0.045, but as the discharge increases the roughness elements are submerged. The best fit to the rating curve and measured data started with a roughness of 0.045 at discharges up to 200 cfs and decreased to 0.026 at a discharge of 7000 cfs according to the following table.

Table of Discharge versus Manning's Roughness Elements for the Pike River Calibration

Discharge	200	500	1000	2000	3000	4000	5000	6000	7000
Roughness	.045	.041	.038	.036	.034	.032	.030	.028	.026

Table of Computed Water Surface Elevations for Discharges up to the 10-Year Flood

Station 70+00	Tailwater Station 73+50	Frequency	Pike Flow	Morpion Flow (by Ratio DA)	Water Surface Elev. At Morpion Bridge
129.8	130.0	April/May	450	90	130.2
131.8	132.1	1.005	1750	340	132.4
133.6	134.2	2-yr	3900	760	134.6
134.4	135.0	5-yr	5200	1010	135.5
134.6	135.5	10-yr	6000	1160	136.0

Figure C-1 shows the computed versus measured water surface profiles for the Morpion Stream which is best supported using a Manning's roughness of 0.035 for developing the tailwater rating curve. Figure C-2 gives the tailwater rating curve for design of the weir at Section or Station 11+03 on the Morpion Stream. Figures C-29, C-30, and C-31 provide the water surface profiles for the 0.5-M, 0.75-M, and 1-M high structures.

HECRAS MODEL INPUT

Downstream Reach Lengths for Morpion Stream (Distances in feet)

Cross Sec. Number	River Station	Left of Bank (LOB)	Channel	Right of Bank (ROB)
1	1311	108	108	108
2	1203	100	100	100
3	1103	97.2	97.2	97.2
4	1006	99.3	99.3	99.3
5	907	101.2	101.2	101.2
6	806	97.5	97.5	97.5
7	708	103	103	103
8	605	75.5	75.5	75.5
9	530	104	104	104
10	426	100	100	100
11	326	97.6	97.6	97.6
12	228	100.6	100.6	100.6
13	128	97.5	97.5	97.5
14	30	30	30	30

Downstream Reach Lengths for the Pike River (Distances in feet)

Cross Sec. Number	River Station	Left of Bank (LOB)	Channel	Right of Bank (ROB)
1	9480	25	50	70
2	9440	1710	1666	1663
3	7770	426	418	403
4	7350	218	354	540
5	7000	180	200	250
6	6800	1900	1950	2000
7	4850	2160	2200	2210
8	2650	740	800	850
9	1850	1850	1850	1850
10 dam	000	0	0	0

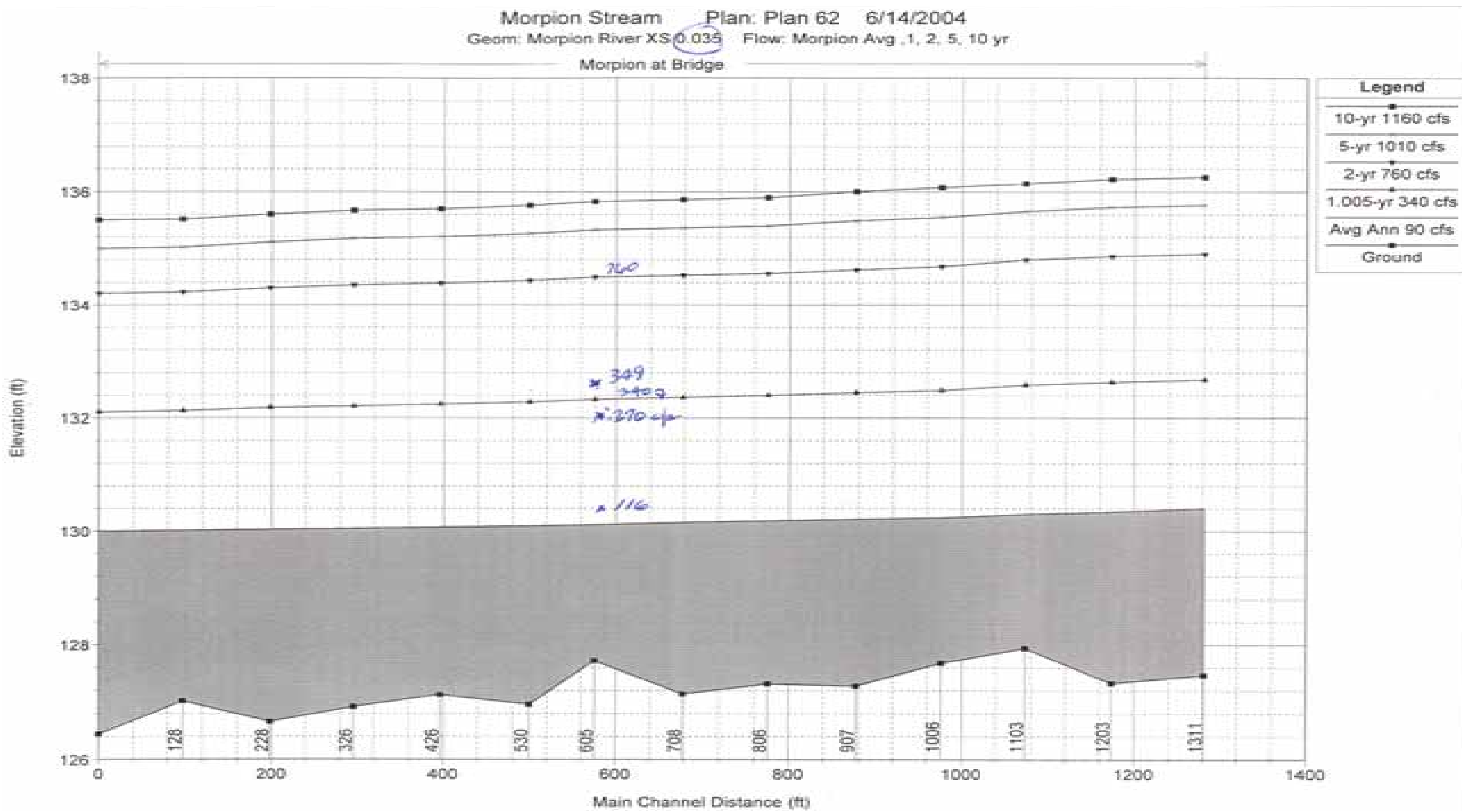

Morpion Stream Plan: Plan 62 6/14/2004
Geom: Morpion River XS 0.035 Flow: Morpion Avg ,1, 2, 5, 10 yr
Morpion at Bridge
Legend
10-yr 1160 cfs
5-yr 1010 cfs
2-yr 760 cfs
1.005-yr 340 cfs
Avg Ann 90 cfs
Ground
Elevation (ft)
Main Channel Distance (ft)
138
136
134
132
130
128
126
0
200
400
600
800
1000
1200
1400
128
228
326
426
530
605
708
806
907
1006
1103
1203
1311

Figure C-1

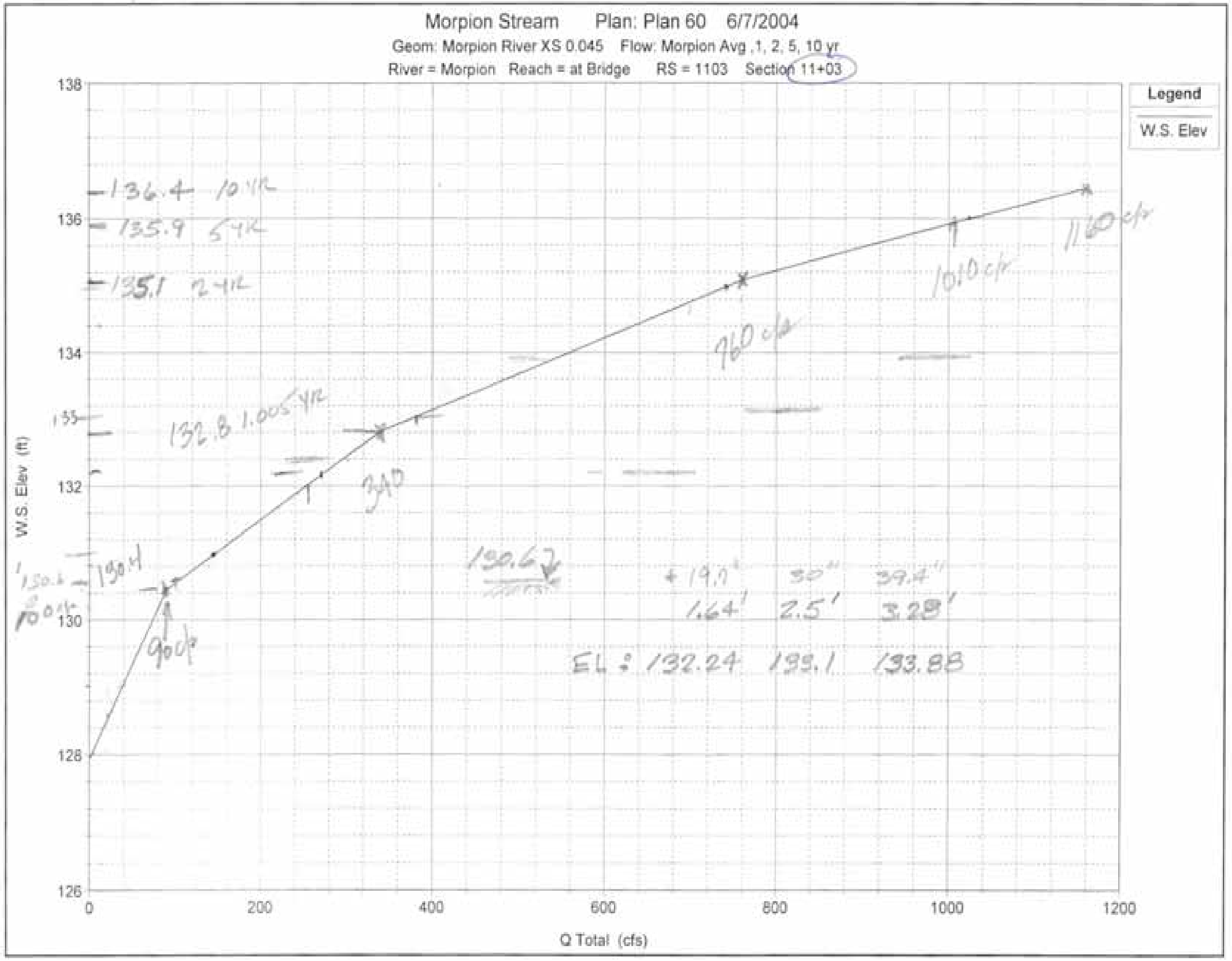

Morpion Stream Plan: Plan 60 6/7/2004
Geom: Morpion River XS 0.045 Flow: Morpion Avg ,1, 2, 5, 10 yr
River = Morpion Reach = at Bridge RS = 1103 Section 11+03
Legend
W.S. Elev
W.S. Elev (ft)
Q Total (cfs)
138
136
134
132
130
128
126
0
200
400
600
800
1000
1200

Figure C-2

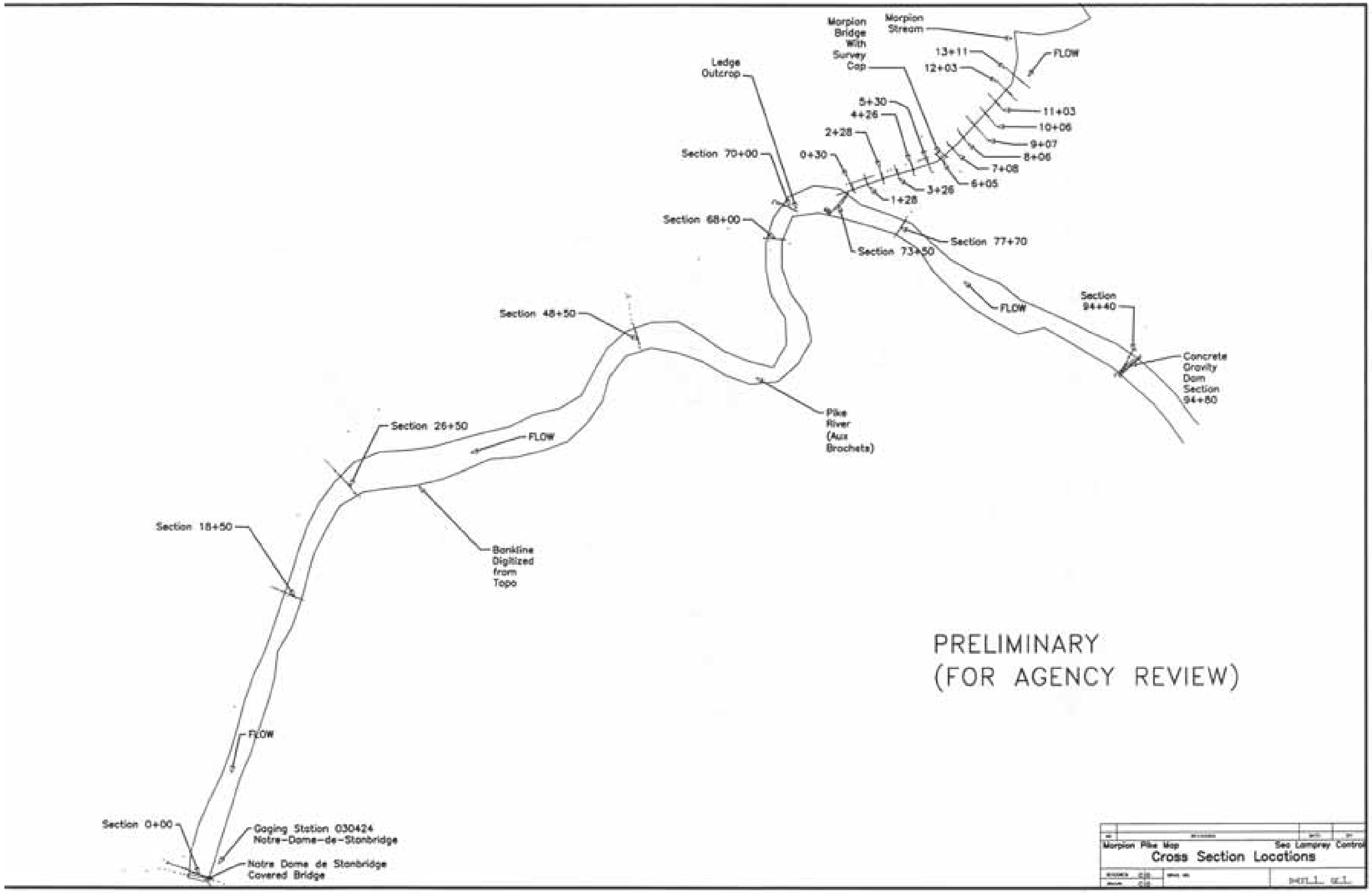
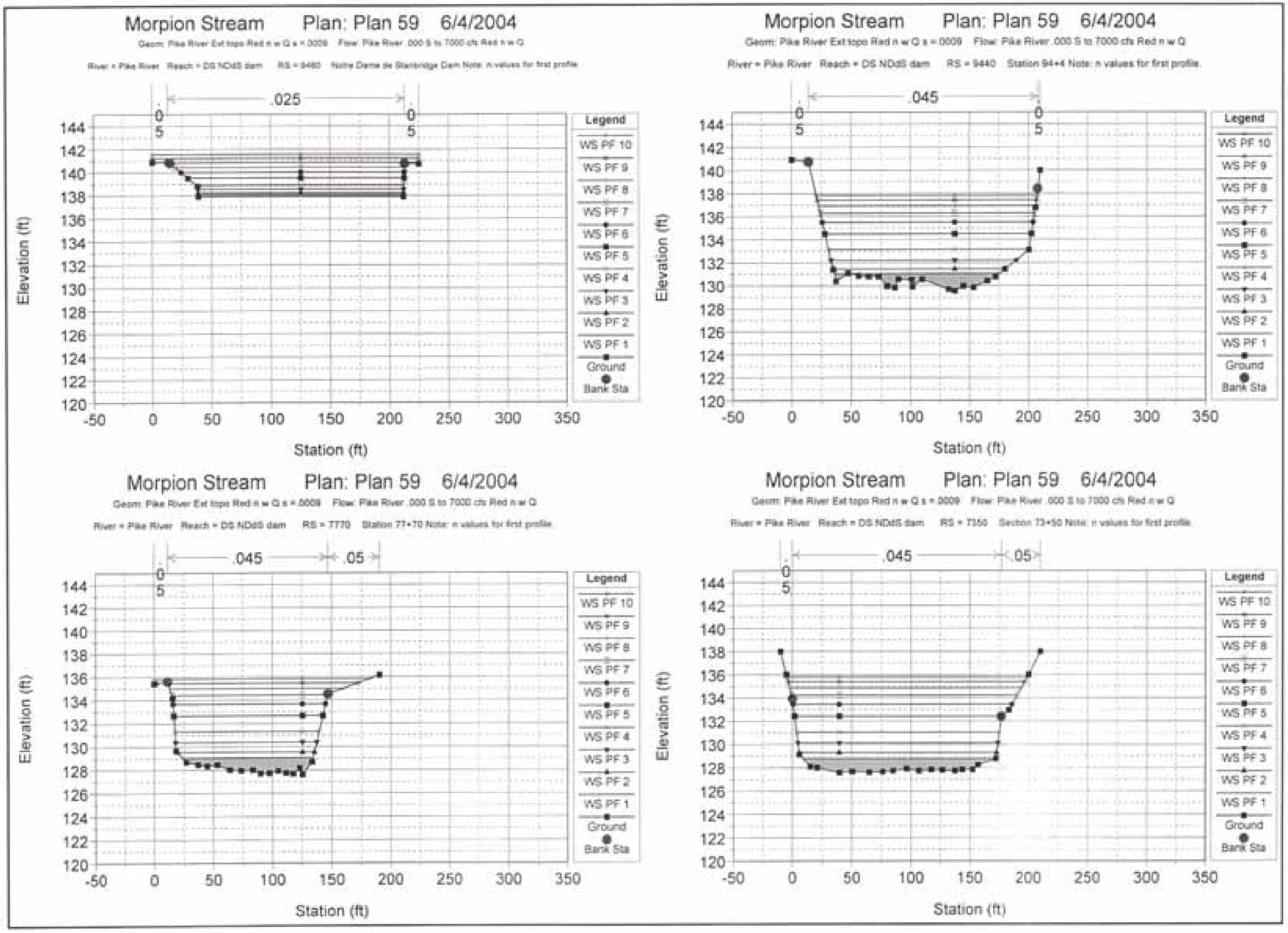
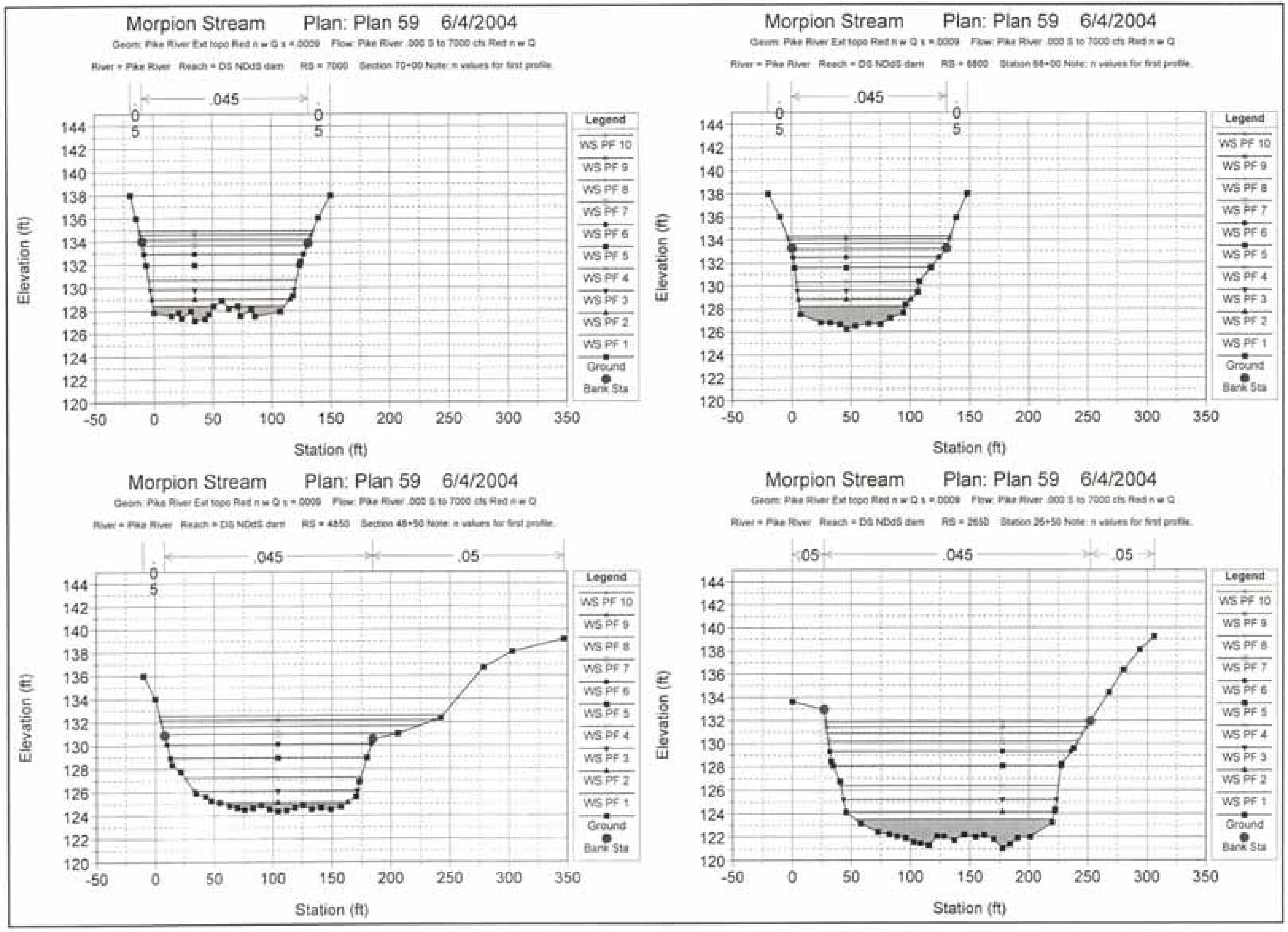

Morpion Stream
Morpion Bridge With Survey Cap
13+11
12+03
FLOW
11+03
10+06
9+07
8+06
7+08
6+05
3+26
1+28
5+30
4+26
2+28
0+30
Ledge Outcrop
Section 70+00
Section 68+00
Section 73+50
Section 77+70
FLOW
Section 94+40
Concrete Gravity Dam Section 94+80
Section 48+50
Pike River (Aux Brochets)
Section 26+50
FLOW
Section 18+50
Bankline Digitized from Topo
PRELIMINARY
(FOR AGENCY REVIEW)
FLOW
Section 0+00
Gaging Station 030424 Notre-Dame-de-Stanbridge
Notre Dame de Stanbridge Covered Bridge
Morpion Pike Map
Sea Lamprey Control
Cross Section Locations

Figure C-3



Figures C-4 and C-5, top row and figures C-6 and C-7, bottom row



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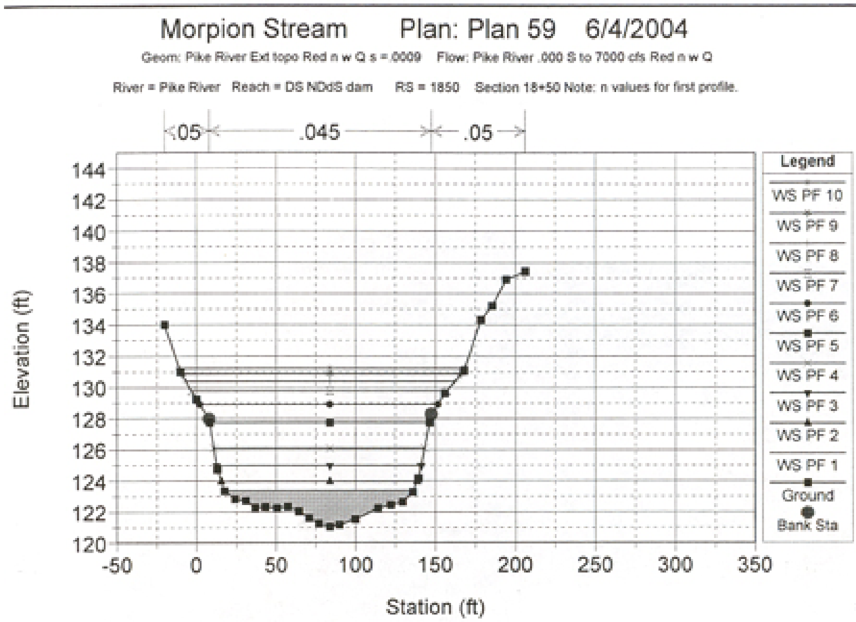
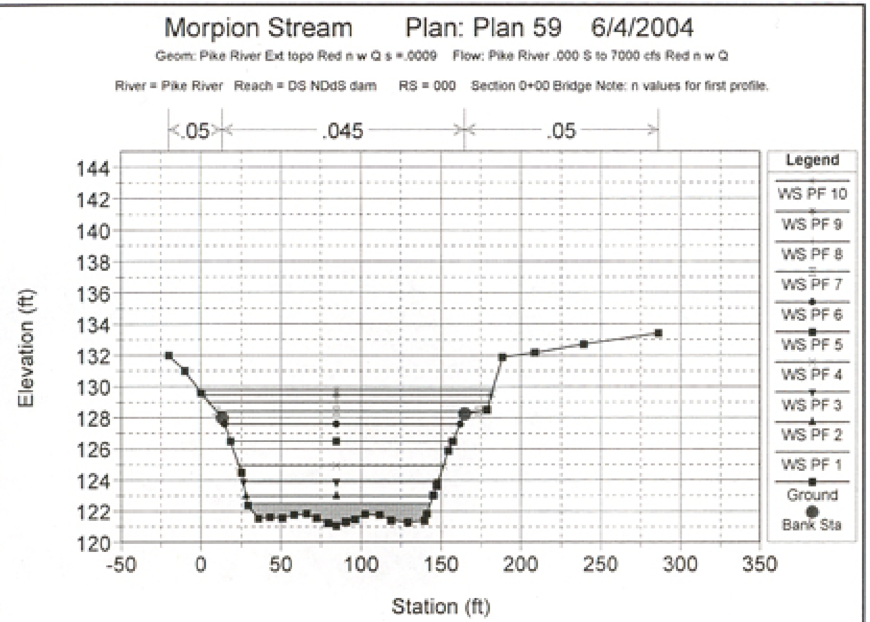




Figures C-12 and C-13

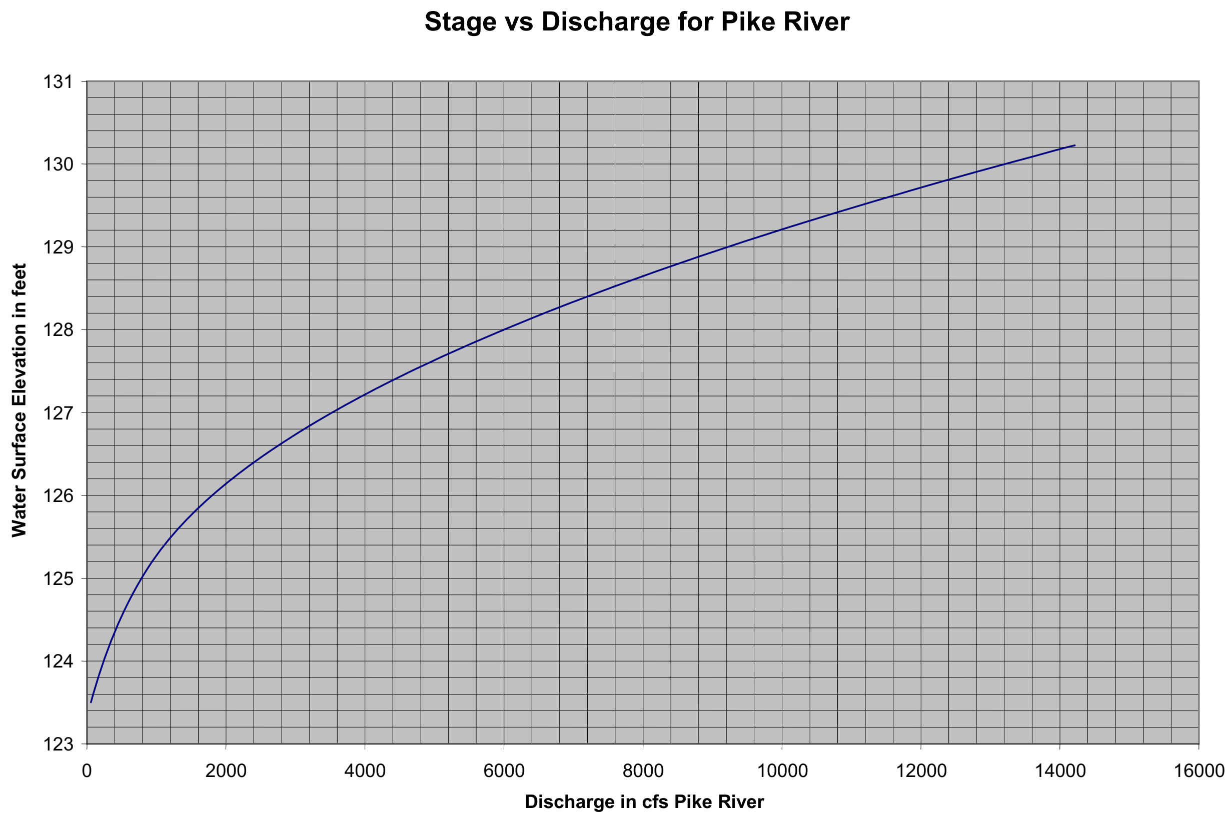


Figure C-14A

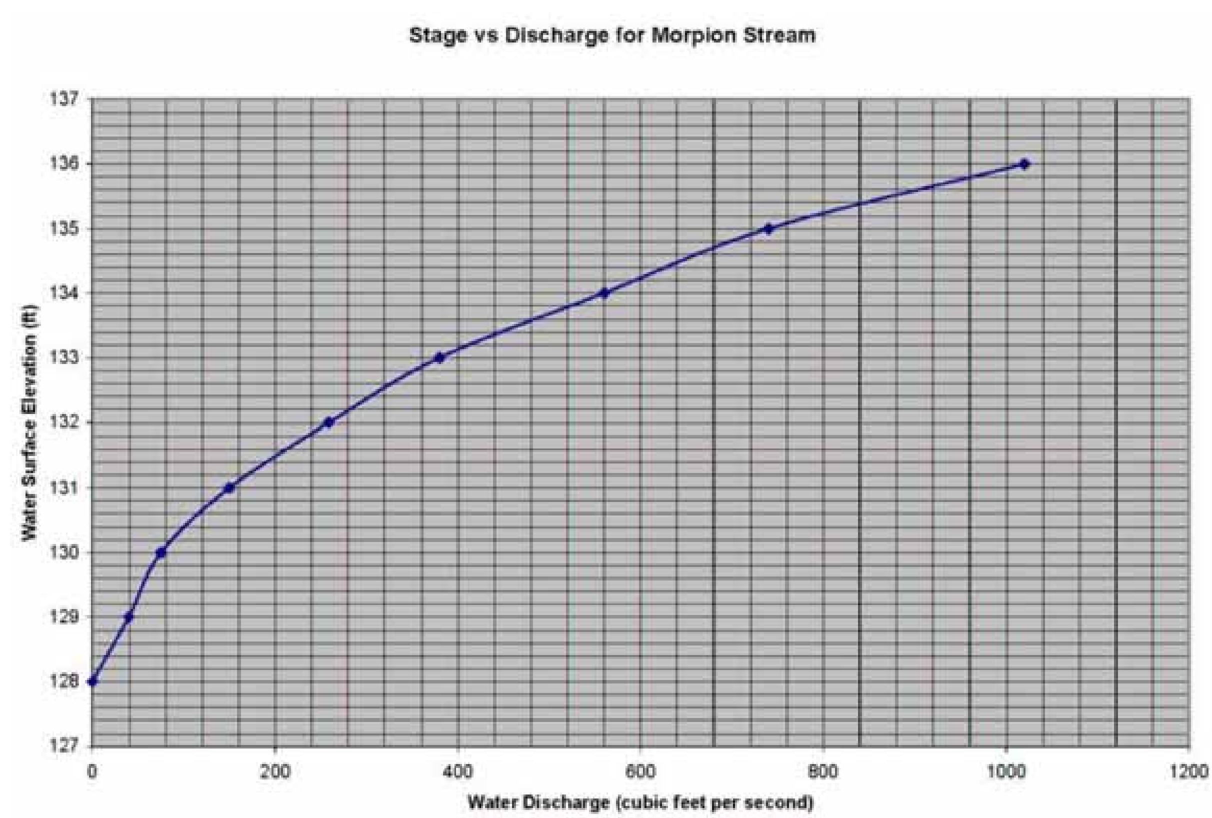
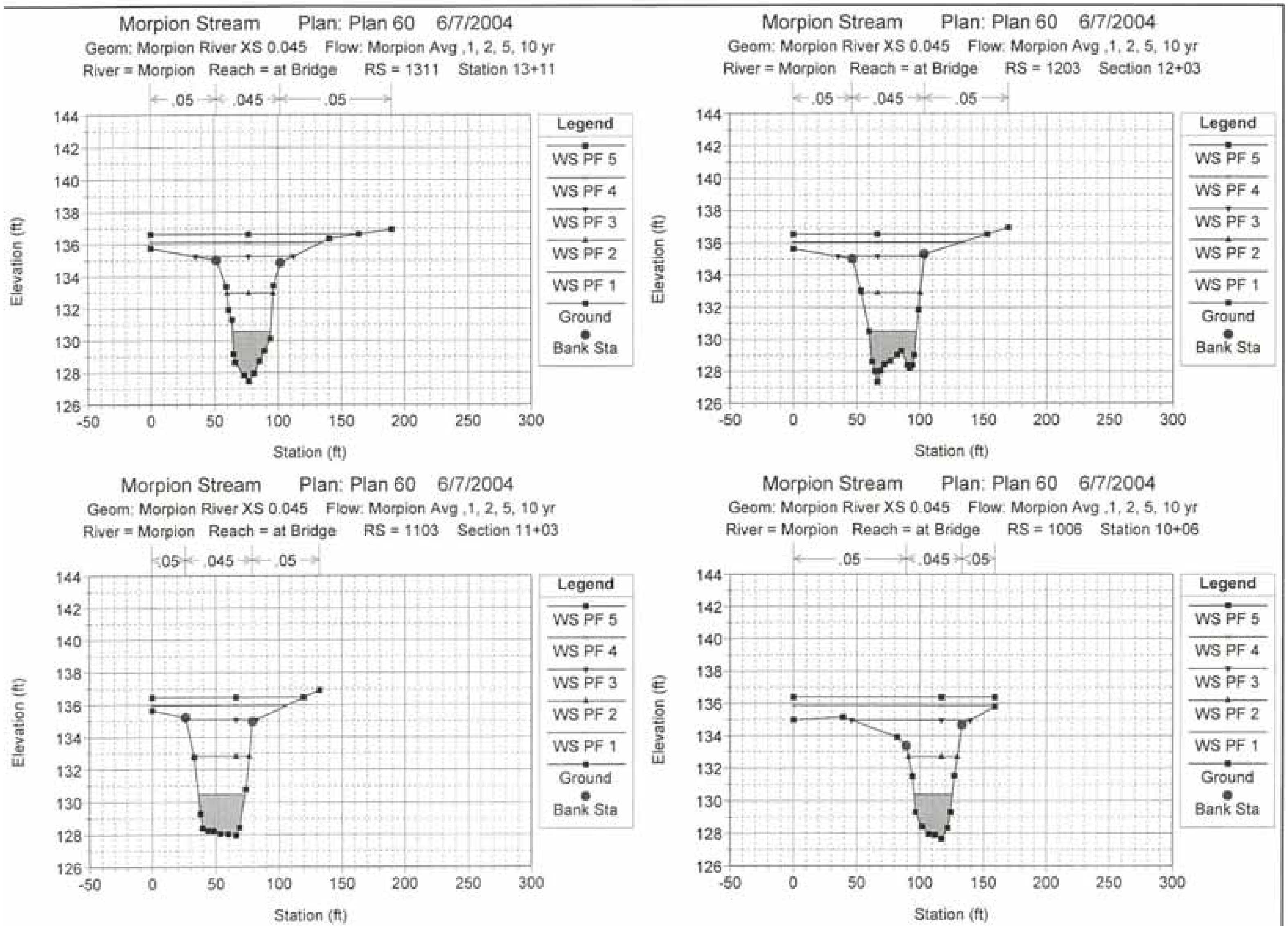
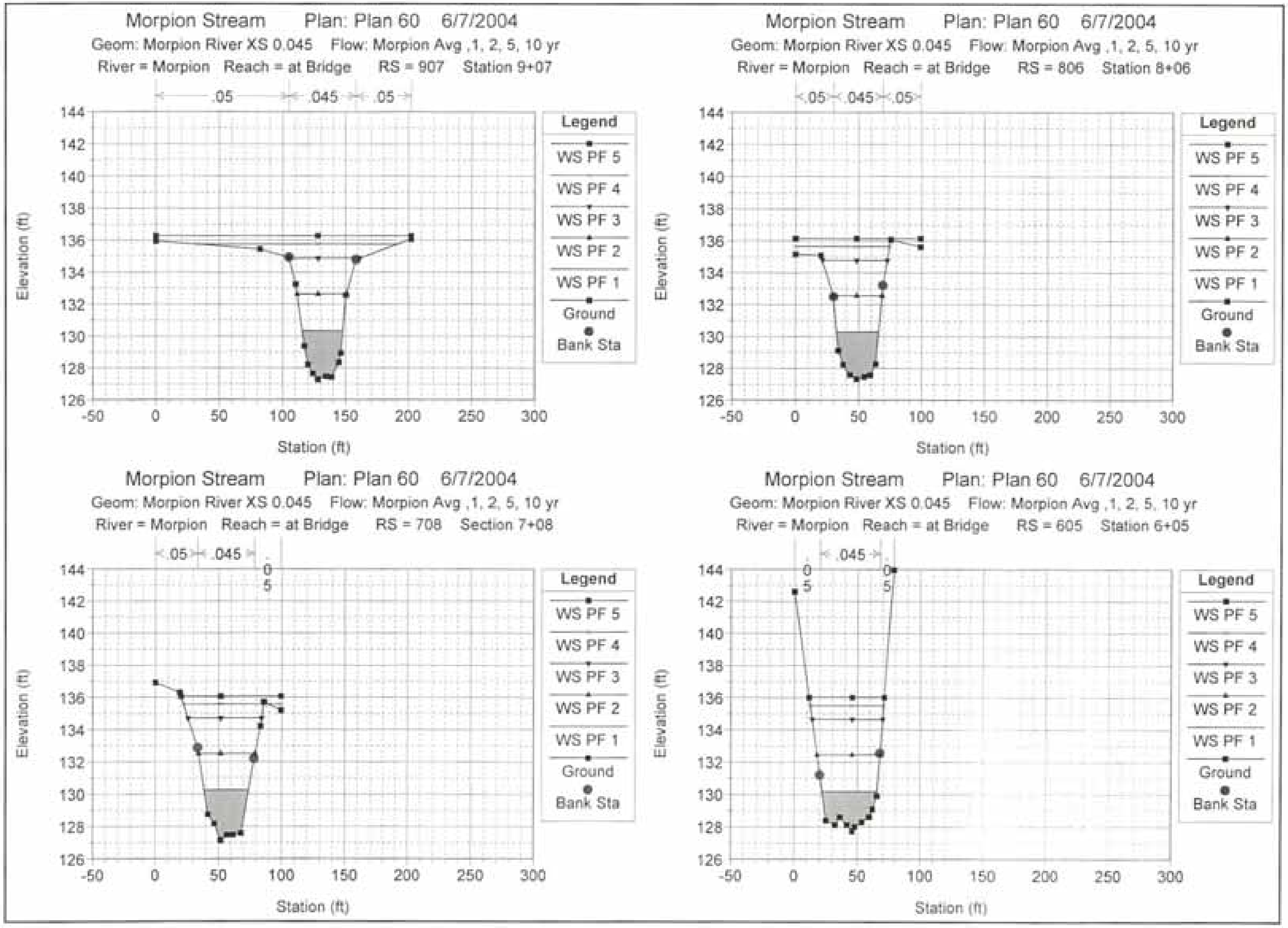


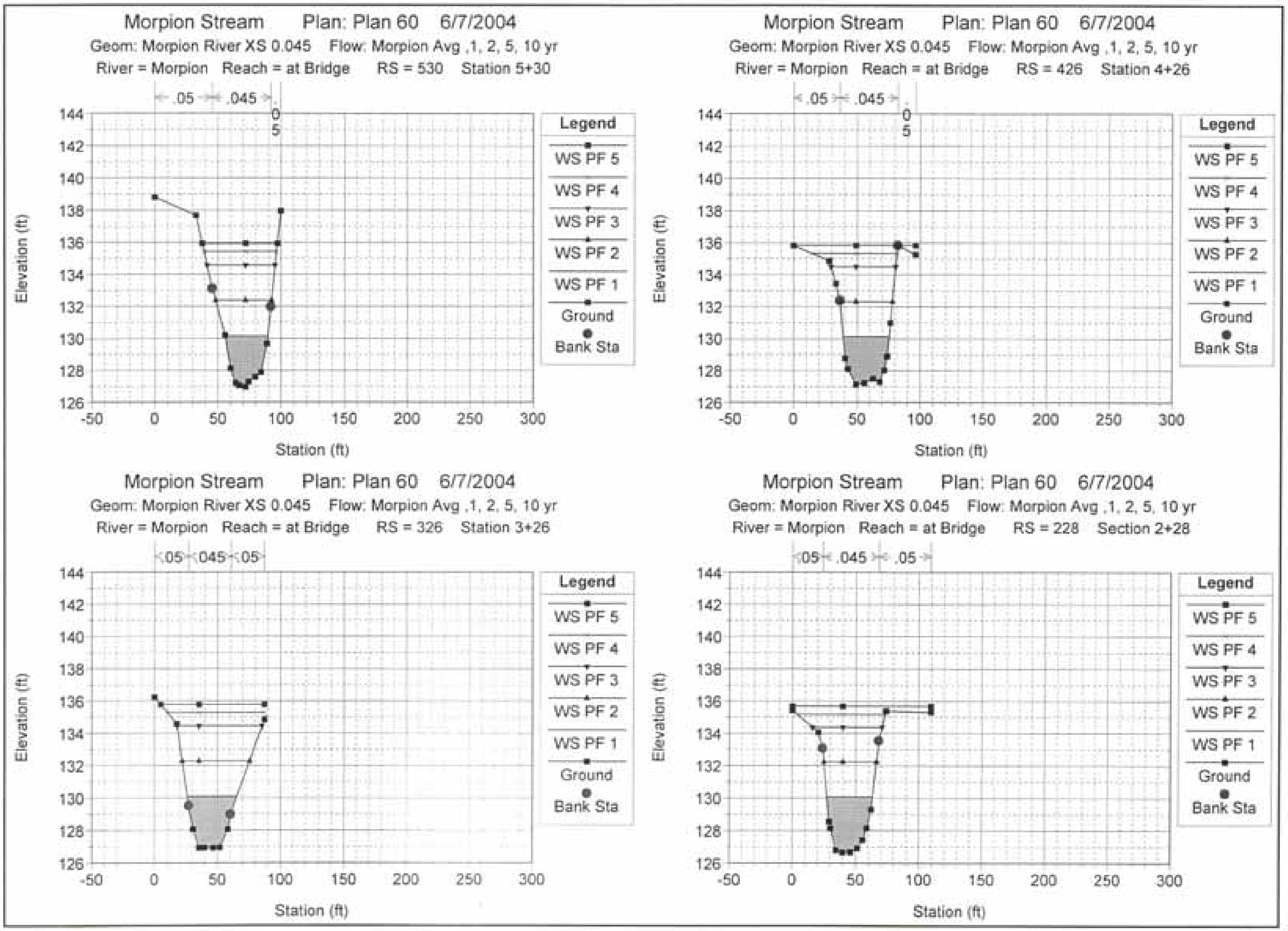
Figure C-14B



Figures C-15 and C-16, top row and figures C-17 and C-18, bottom row



Figures C-19 and C-20, top row and figures C-21 and C-22, bottom row



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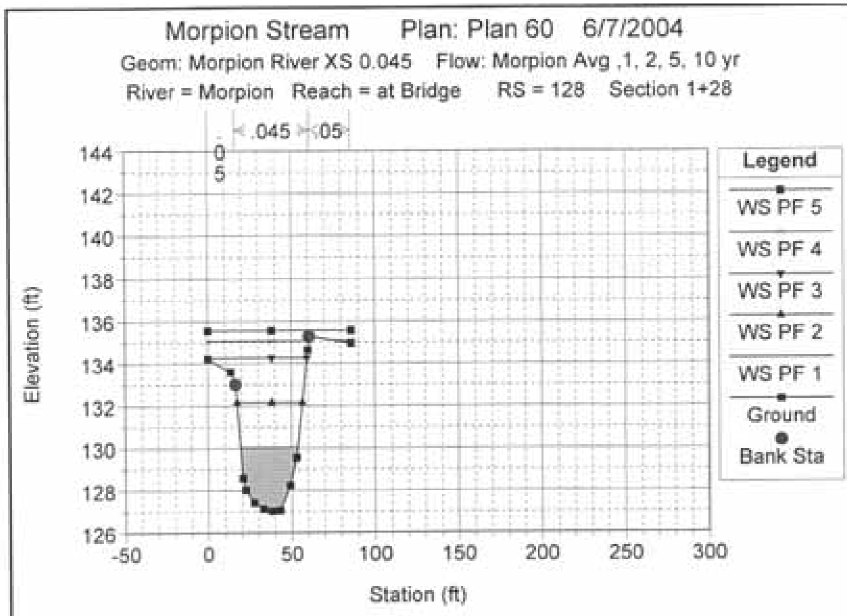
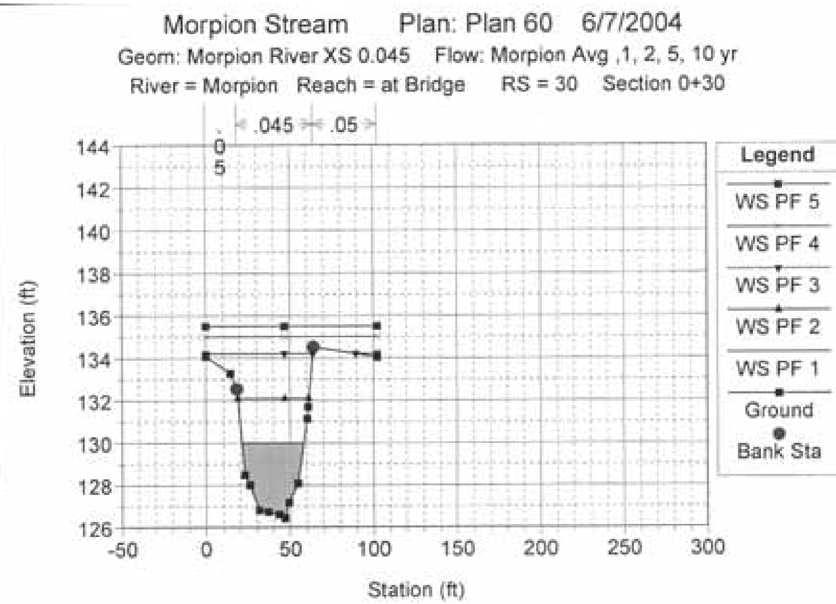




Figures C-27 and C-28

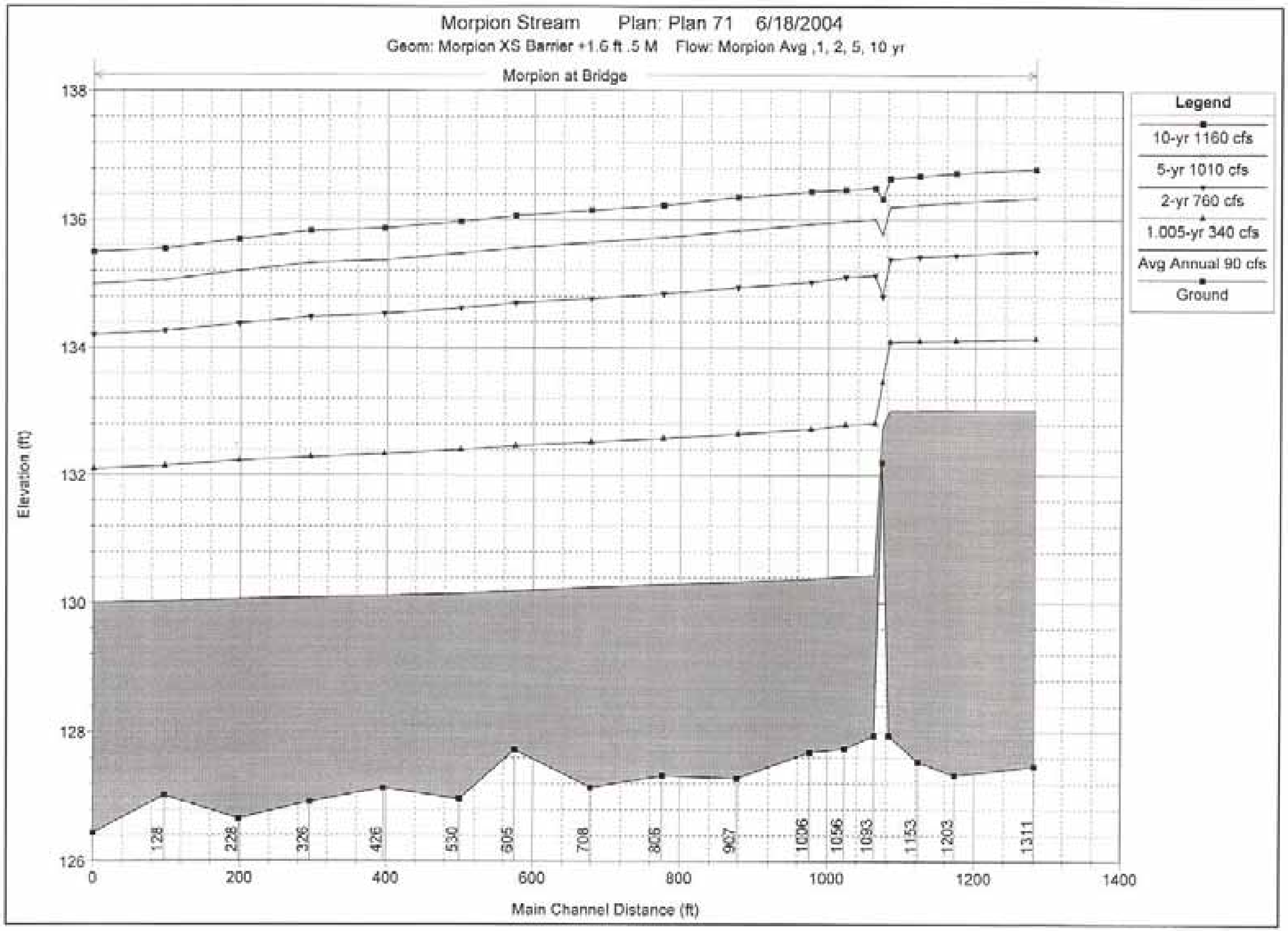
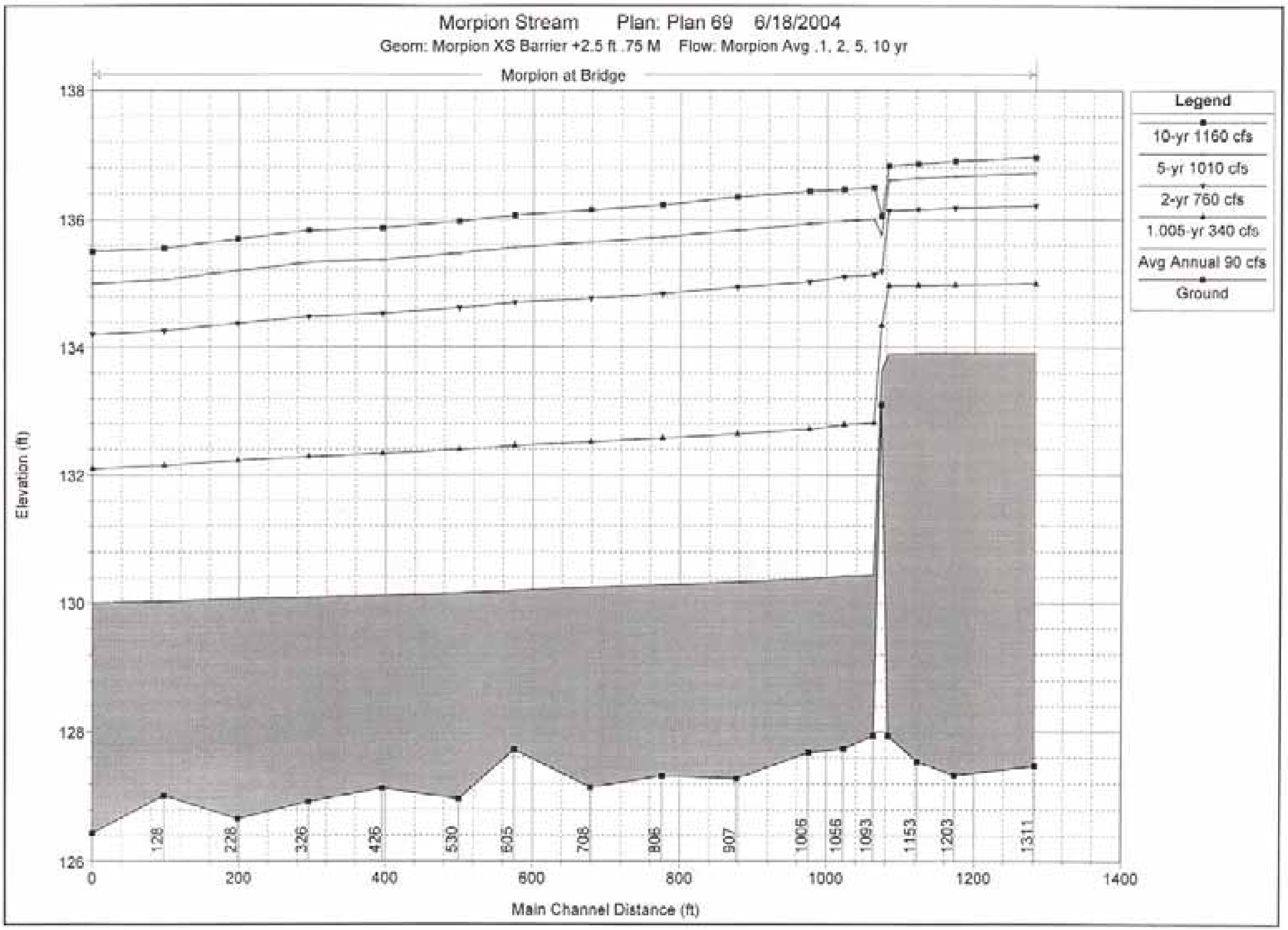
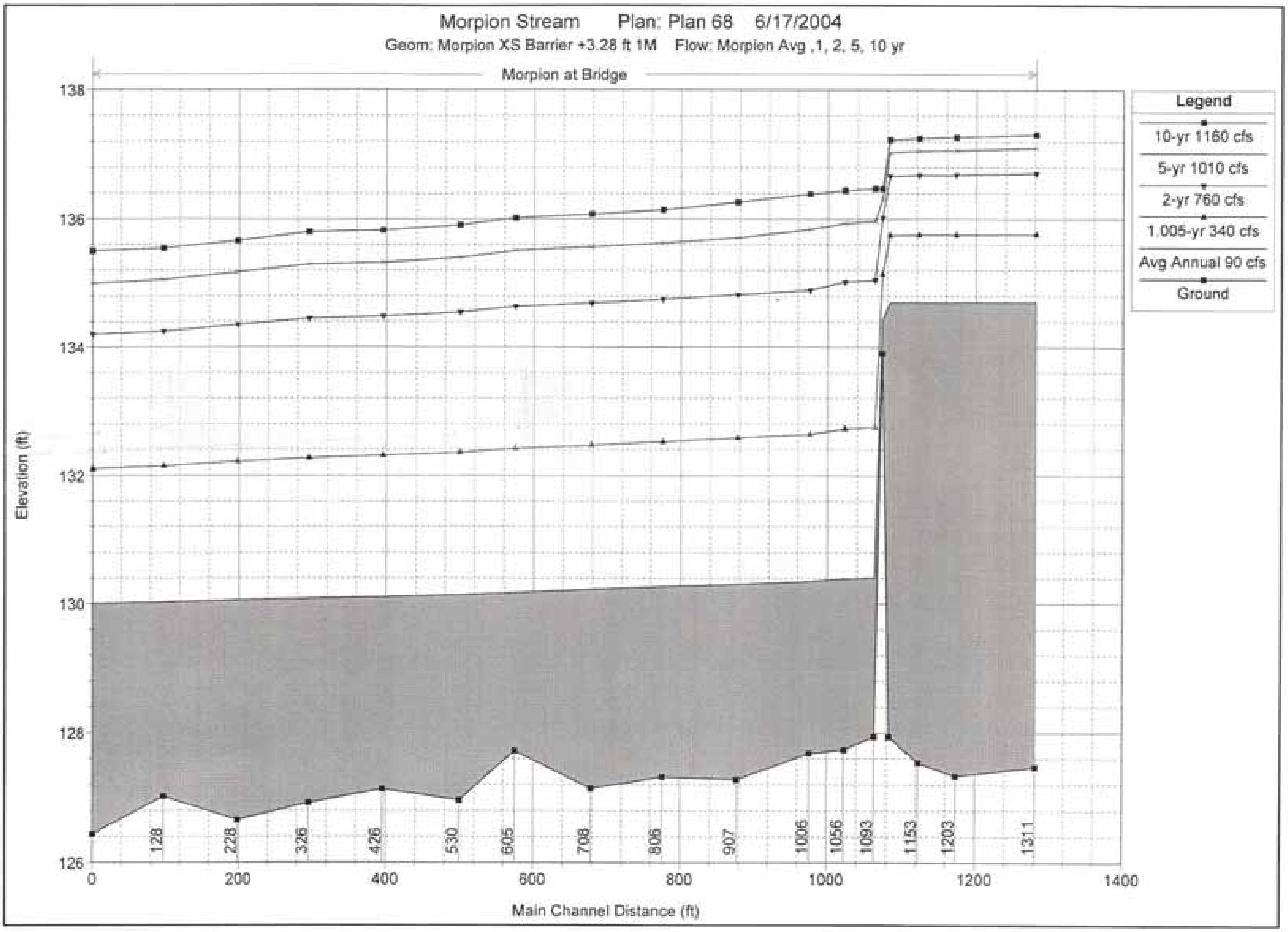

Morpion Stream Plan: Plan 71 6/18/2004
Geom: Morpion XS Barrier +1.6 ft .5 M Flow: Morpion Avg ,1, 2, 5, 10 yr
Morpion at Bridge
Legend
10-yr 1160 cfs
5-yr 1010 cfs
2-yr 760 cfs
1.005-yr 340 cfs
Avg Annual 90 cfs
Ground
Elevation (ft)
Main Channel Distance (ft)
138
136
134
132
130
128
126
0
200
400
600
800
1000
1200
1400
128
228
326
426
530
605
708
806
907
1006
1056
1093
1153
1203
1311

Figure C-29



Morpion Stream Plan: Plan 69 6/18/2004
Geom: Morpion XS Barrier +2.5 ft .75 M Flow: Morpion Avg .1, 2, 5, 10 yr
Morpion at Bridge
Legend
10-yr 1160 cfs
5-yr 1010 cfs
2-yr 760 cfs
1.005-yr 340 cfs
Avg Annual 90 cfs
Ground
Elevation (ft)
138
136
134
132
130
128
126
128
228
326
426
530
605
708
806
907
1006
1056
1093
1153
1203
1311
0
200
400
600
800
1000
1200
1400
Main Channel Distance (ft)

Figure C-30



Morpion Stream Plan: Plan 68 6/17/2004
Geom: Morpion XS Barrier +3.28 ft 1M Flow: Morpion Avg ,1, 2, 5, 10 yr
Morpion at Bridge
Legend
10-yr 1160 cfs
5-yr 1010 cfs
2-yr 760 cfs
1.005-yr 340 cfs
Avg Annual 90 cfs
Ground
Elevation (ft)
138
136
134
132
130
128
126
128
228
326
426
530
605
708
806
907
1006
1056
1093
1153
1203
1311
0
200
400
600
800
1000
1200
1400
Main Channel Distance (ft)

Figure C-31