Final Technical Report

Suncook River Avulsion, Geomorphology-based Alternatives Analysis

Epsom, New Hampshire

Prepared for:	Town of Epsom, New Hampshire & NH Department of Environmental Services
Prepared by:	**VHB/Vanasse Hangen Brustlin, Inc.** **Bedford, New Hampshire**
In association with:	**Parish Geomorphic** and **Kleinschmidt Associates**

May 28, 2008

Funding for this project was provided in part by a grant from the NH Department of Environmental Services with funding from the US Environmental Protection Agency under Section 319 of the Clean Water Act. Additional funds were provided by the Town of Epsom and the Friends of the Suncook River.

Table of Contents

ES Executive Summary

1.0 Geomorphic Assessment

2.0 Alternatives Descriptions

List of Figures

List of Tables

Executive Summary

A. Introduction

An extreme rain event occurred on May 15th and 16th 2006 in New Hampshire which resulted in a state-wide flood. The Suncook River, which flows southwest towards the Merrimack River from its headwaters at Crystal Lake in Gilmanton, experienced a 100-year flood event. The high flood waters caused the Suncook River to change course (an event known as an "avulsion") in the Town of Epsom near the Huckins Mill Dams, upstream of Bear Island. Prior to the river changing course, just west of the avulsion site, the Suncook River formerly split into two channels at the Huckins Mill Site: a primary (west) channel and a smaller, secondary (east) channel. As a result of the 2006 avulsion, the Suncook River now flows through a gravel pit to the northeast of Bear Island (known as "Cutter's Pit") before rejoining a portion of a pre-existing secondary channel that formed the eastern margin of Bear Island. Nearly two miles of former channel now lays abandoned, including 1.5 miles of the primary channel that formed the western margin of Bear Island. Aside from small pools and seeps, and contribution from a small tributary, the now-abandoned portions of the Suncook River are not expected to maintain significant year-round flow. The new channel is approximately 1.0 mile long, of which about 0.44 mile is newly eroded valley.

The overall goal for this study is to provide sufficient information to the community (including property owners as well as local, state and federal stakeholders) to allow an informed decision as to what course of action should be followed to prevent further impacts to private property, ecological resources, and water quality. This goal will be met when a restoration plan is produced that recommends a preferred alternative to either return river to historical channels or work with existing channel to find a stable endpoint that minimizes potential future damage to infrastructure and eliminates water quality impairments.

B. Summary of the Geomorphic Assessment

A field survey of the river was completed during July and August 2007. This work included about 30 detailed survey "cross-sections" in the former and new river channels from US 4/NH 9/US 202 to the Webster Park town beach just south of Short Falls Road. An undisturbed portion of the river (a "reference reach") further upstream was also surveyed to provide comparative information.

For purposes of discussion, several project reaches were defined:

- The **"Old Primary Channel"** is the main part of river channel prior to the avulsion, *i.e.*, the branch of the Suncook River that forms the western boundary of Bear Island.
- The **"Old Side Channel"** is the smaller branch of the Suncook River that forms the eastern boundary of Bear Island from the second Huckins Mill Dam to the channel's confluence with the New Channel.
- The **"New Channel"** includes the avulsion site as well as the channel eroded through Cutter's gravel pit. It ends at the point where it meets ("at the confluence of") the "Old Side Channel," defined above.
- The **"Confluence Area"** is the portion of the study area at and below the confluence of the New Channel and the Old Primary Channel.

Below, the key findings of the assessment are outlined:

The river has been quite stable over the last 50 years. Although the river is quite winding in places, an analysis of topographic maps and aerial photographs from 1921, 1953, and 2003 illustrates that the river channel has been quite stable over the recent past. Generally, meander bends at and above the avulsion site migrated at a negligible rate over the last 50 years.

An active headcut was initiated by the avulsion and appears to be actively migrating upstream. When the elevation of a streambed is lowered by either natural or man-made reasons, a "headcut" can result. A headcut is a type of erosional feature seen in flowing waters where a deep incision of the streambed forms, lowering the streambed and usually causing the riverbanks to erode and collapse. The erosion moves upstream steadily until it either achieves an equilibrium or encounters hard materials that will not erode (*e.g.*, bedrock). The survey of the Suncook completed during this study found that such a headcut has been initiated on the mainstem of the Suncook, as well as on the Little Suncook River and Leighton Brook. All of these headcuts are active.

Severe degradation has occurred at the avulsion site, which means that the elevation of the new stream channel is up to 12 feet lower than the old channel bed. This channel degradation has moved upstream to a point north of the confluence with the Little Suncook (*i.e.*, an active "headcut" is moving upstream). The streambed near the mouth of the Little Suncook appears to be as much as three feet lower than before the avulsion. *This bed erosion has contributed to the collapse of an old stone bridge on the railroad grade crossing of the Little Suncook River and is cause for concern for the existing US 4 Bridge just to the north. Extreme headcutting is also evident on Leighton Brook where the bed of Leighton Brook has fallen as much as 20 feet.*

The New Channel is relatively stable for flows equal to or less than "bankfull" discharge but prone to excessive erosion and sedimentation for flows exceeding "bankfull." Calculations of the power of the stream to move sediment in the New Channel indicate that the New Channel is relatively stable for discharges up to and including "bankfull." One such calculation, the "critical discharge," which measures the flow needed to move sediment (specifically the D_{50} or median particle size) in a particular location in the stream, shows that flows close to "bankfull" are required to initiate movement of most of the bed sediment. Specifically, the "critical discharge for the New Channel is approximately 91 percent of the "bankfull" discharge (*i.e.*, a flow that would be expected to occur once every 1.5 to 2.0 years), which suggests that the existing "bankfull" channel may already be reasonably close to the appropriate dimensions.

It's important to remember that The New Channel consists primarily of course sand and very fine gravel. While the critical discharge calculation indicates that the "bankfull" channel may be relatively stable, discharges exceeding "bankfull" can be expected to result in excessive erosion and sedimentation because the "bankfull" channel is still entrenched (not connected to an adequately wide floodplain) with very high unstable sandy banks. This unstable condition will remain until the river carves an adequate floodplain through the valley and attains a new dynamic equilibrium. While it is impossible to predict exactly how long it would take the river to reach equilibrium, observations by the assessment team, as well as experience with similar sites, leads to the conclusion that the process could take decades. Hence, if the New Channel is left to achieve equilibrium on its own, higher than normal levels (pre-avulsion levels) of sediment can be expected to be transported downstream for many years to come.

Recent surveys of the river indicate that the New Channel is rapidly adjusting laterally. A comparison of aerial photography from 2006 to 2007, as well as GPS survey data collected by the NH Geological Survey, indicates that a large meander bend in the New Channel has been rapidly migrating, contrary to the relative stability seen in the river planform prior to the avulsion. From 2006 to 2007, this meander bend migrated about 150 feet south.

Downstream of the avulsion, the primary adjustment process is one of aggradation (deposition). Field work revealed that long reaches downstream of the confluence of the new channel and the old secondary channel are 50% to 90% filled with sediment. This means that the streambed elevation has increased, which allows the stream to overtop its banks under relatively small flows.

Downstream of the avulsion, aggradation of fine material has raised the river bed such that the river bed is at the same elevation as the surrounding floodplain. Aggradation north of Round Pond has forced flood flows to spread out onto the floodplain into areas that were once considered outside of the 500 year floodplain, as was observed to occur in April 2007. Flows were running in newly formed flood chutes adjacent to the municipal well at this time.

The current volume of sediment in the channel below the avulsion site presents the risk that a secondary avulsion may occur. This possibility is perhaps greatest below the confluence of the old and new channels, near Round Pond. There is a high risk of large scale changes at the pond location, which would have unknown consequences for the ecology of this unique pond. Additionally, there is a risk of avulsion to the west through an agricultural field at the meanders in the floodplain north of Short Falls Road.

The Old Primary Channel and the Suncook River above the US 4 bridge are stable. Critical discharges in the Old Primary Channel and the Reference Site (which is near the Chichester/Epsom town line) occurred at approximately 295% and 172% respectively of bankfull conditions, indicating that these channels remain stable (Reference Site) or were stable before the avulsion (Old Primary Channel). The erosion threshold calculated for the Old Primary Channel resulted in a higher critical discharge than for the Confluence Area. The Old Primary Channel contained much coarser material that was harder to move and resulted in a more stable channel overall.

The New Channel bypasses the Huckins Mill Dams, which has eliminated the impoundment that these dams once created. Prior to the avulsion, the Huckins Mill Dams created an impoundment at least two miles long, which raised the river and created a "lacustrine" (lake-like) environment of deep, very slowly flowing water. Property owners became accustomed to this character of the river. Since the avulsion, however, the river flow has returned, with shallower depths. The loss of the impoundment might also have affected adjacent ponds and groundwater conditions upstream of the dams.

The findings of the Geomorphic Assessment were used to develop a range of alternatives to address the stability and flooding issues identified during the assessment.

C. Summary of the Alternatives

One key element of the study is to develop a range of alternatives that could address the flooding and stability issues related to the avulsion. Based on the geomorphic survey, as well as discussions with interested technical partners and members of the public, four main alternatives were developed and refined for the analysis.

C.1 Alternative 1 - No Action

This alternative involves allowing the Suncook River and its tributaries to achieve equilibrium through natural adjustment over time without any substantial intervention. The consequences of the No Action Alternative are discussed in Section D, below.

C.2 Alternative 2 - Strategic Treatment of Degrading and Aggrading Stream Reaches

Alternative 2 involves leaving the river channel in its current position but addressing erosion and sedimentation at strategic locations along the system. Specifically, control of headcutting in the main channel between the US 4 bridge and the avulsion site would be attempted through installation of two rock "cross-vane" structures in conjunction with channel shaping and grading to create bankfull benches. Likewise, headcutting in the Little Suncook and Leighton Brook might also be adequately treated through installation of appropriately placed boulder grade control structures in conjunction with minimal grading and shaping of the existing channel. Based on preliminary information, it appears that two structures would be needed in the Little Suncook, while as many as four structures may be needed in Leighton Brook.

Additionally, stream reaches downstream of the New Channel which have filled with sediment would be excavated to restore cross-sectional area and appropriate sediment transport capacity. An estimated 32,000 cubic yards of unconsolidated material will need to be removed from about 5,000 linear feet of the existing channel.

It is also recommended to further investigate the degree to which the old railroad grade on the east side of the river acts as a floodplain barrier. If it is found to be a barrier, modification of the railroad grade by installing floodplain culverts or by excavating portions of the grade is recommended to allow the river to access its floodplain.

C.3 Alternative 3 - Alternative 2 plus Restoration of New Channel

Alternative 3 would implement Alternative 2 as defined above <u>and</u> restore the remainder of the New Channel to its equilibrium endpoint. This would involve determining and implementing the river's most probable stable form (dimension, pattern and profile), given existing hydrologic and sediment regimes and site geology. More specifically, the geomorphic assessment found that the New Channel is an "F5" stream type. An "F5" stream tends to be relatively straight and wide, and to have steep banks which are deeply entrenched. Since these stream types generally evolve to a narrower, more sinuous and less incised

"C5" stream type, it would be possible to reshape the New Channel so that it is closer to its equilibrium. This alternative would also create a floodplain with an average width, including left and right overbank areas, on the order of 400 to 500 feet. The intent of this alternative would be to provide self-maintaining channel stability and minimize the production of excess sediment through the New Channel.

Alternative 3 would also require dredging of approximately 32,000 cubic yards of sediment from the river, as described previously for Alternative 2. The installation of rock cross-vanes above the avulsion site and on the Little Suncook and Leighton Brook would also likely be required, as would the modification of the railroad grade.

C.4 Alternative 4 - Restore the Suncook to pre-May 2006 Avulsion Position

Restoring the Suncook River to its original channel would require a replacement of the river bank that failed during the May 2006 avulsion by way of an engineered lateral dam structure. Considering that an estimated 150,000 cubic yards of sediment washed out of the bank during the event, the construction of a new "bank" will require a massive and highly engineered structure to restore the channel. Under Alternative 4, this would be accomplished by building a diversion dam across the Suncook River to direct flow back into the original channel. The two Huckins Mill Dams are assumed to remain in place, but their removal would allow for a smaller, less expensive structure.

Similar to Alternatives 2 and 3, removal of excess sediment would be required in the channel segment that runs between the outfall of the Old Secondary Channel and confluence with the Old Primary Channel in order to restore pre-avulsion capacity through this reach. And, stabilization of Leighton Brook would be required, similar to other alternatives.

This alternative includes two options that would achieve similar results:

- **Alternative 4A** – A diversion structure (1,300 feet long by 25 feet high) could possibly be built upstream of the avulsion site, at a location that would cut off the meander in this reach.
- **Alternative 4B** - A diversion structure (800 feet long by 30 feet high) could also be built at the location of the avulsion, essentially replacing the bank that failed in May 2006.

It was determined that the crest of the structure in either location would be at El. 340 feet, which is the 500-year flood level plus 1 foot of "freeboard." The dam at either location would be classified as a “Class B – Significant Hazard” structure under state dam safety rules.

D. Evaluation of Alternatives

A draft evaluation of the four main alternatives consists primarily of a discussion of costs and benefits associated with each alternative. Natural and anthropogenic site constraints affecting each alternative are identified and discussed. These include regulated floodplains and wetlands and infrastructure such as buildings, utilities, and roads and bridges.

D.1 Alternative 1 – No Action

Alternative 1, the “No Action” alternative, was included in the study to provide a baseline against which other alternatives can be assessed, and to allow for consideration of whether public funds should be expended on any remedy at all. The geomorphic assessment, however, leads to the conclusion that the No Action Alternative would allow continued instability and flooding, which could reasonably be expected to create further damage.

Potential consequences of the No Action Alternative include:

- The continued headcutting in the main river channel between US 4 and the Avulsion Site, as well as in tributaries feeding the main channel from the east, such as the Little Suncook River and Leighton Brook.
- As portions of the river channel become more incised (cut downward, thereby deepening the river channel) and cutoff from the historic floodplain, streambank erosion/failure will increase as the river seeks a new dynamic equilibrium at a lower elevation in the valley floor.
- The current volume of sediment in the channel below the avulsion site raises the possibility that a secondary avulsion may occur. This possibility is perhaps greatest below the confluence of the old and new channels, where an avulsion may cause the river to take a new route through Round Pond.
- Downstream migration of sediment from the New Channel could be deposited even further downstream, outside of the study area. The potential consequence of this sediment on flooding of adjacent properties is not well understood at this time, but is under study by the USGS.
- Continued headcutting raises a serious concern about the long term stability of the US 4/US 202/NH 9 bridge crossing.
- Lateral adjustment of the river banks can be expected to continue to damage the agricultural property to the east of the river as well as the residential property to the west.

- Continued headcutting could lead to further damage to the railroad grade located to the east of the river. The grade, which is evidently used as a recreational path, is already impassible at the Little River due to the existing damage. Similar damage to the railroad culvert on Leighton Brook could have a similar effect.
- Continued downstream sedimentation could have adverse effect on aquatic organisms, fish habitat, and the brook floater mussel, a rare species in NH.

While this alternative has a major advantage over others with regard to costs, it is not the recommended solution because of the risks described above.

D.2 Alternative 2 – Strategic Treatments

While all of the "Build" alternatives are costly, Alternative 2 involves the least amount of work and is therefore the least expensive (see Section D.5 below). It seeks to treat the two primary problems: 1) the headcutting of the river and its tributaries, and 2) the potential for a future avulsion at Round Pond.

Rock Cross-vanes

Because the scope of this project does not include geotechnical explorations, it is impossible to say with any certainty whether the headcutting will continue, and if so, how much additional erosion would result. However, the material that is currently visible on the surface of the riverbed above the avulsion site appears to be inadequate to completely arrest the headcut. For this reason, the installation of up to nine (9) grade control structures (rock vanes or similar) in certain locations is recommended in the mainstem and tributaries as a minimum measure. Potential effects of these cross-vanes are as follows:

- Cross-vanes such as the type recommended have been shown to arrest headcutting in numerous rivers and streams around the country and it is anticipated that they will be effective in this case.
- The installation of the rock cross-vanes should not have permanent adverse impacts on adjacent landowners, although certain areas would be subject to disturbance during the construction. Access to the mainstem of the Suncook and even the Little Suncook is fairly good *via* the east side of the river.
- On Leighton Brook, however, access is more constrained and the construction would require clearing of a forested area, although this forest is quite young. Construction of the cross-vanes would require temporary construction easements from affected property owners.
- The cross-vanes would not change the floodplain, and would therefore not have any influence on the tendency of the river to flood. While there would be some short-term ecological impact during construction of the cross-vanes, that impact is expected to be small and short-lived.

Restoration of Bankfull Channel Downstream of Avulsion

As discussed in the geomorphic assessment, a large amount of sediment has deposited in the channel downstream of the avulsion – particularly above the meanders north of Short Falls Road. In much of this area, the channel has aggraded with sand such that the river bed is at the same elevation as the floodplain topography. This is forcing flood flows to spread out onto the floodplain into areas that were once considered outside of the 500 -year floodplain. Evaluation of this risk and of the recommended solution follows:

- If left to evolve naturally and over time, there is a risk of large scale changes to channel form near Round Pond. Such an avulsion would have additional impacts to landowners who have already been impacted as a result of the 2006 and 2007 floods.
- If this avulsion were to occur, the pond may act as a sediment sink which, ironically, might attenuate some of the downstream concerns. However, it would likely cause or accelerate the eutrophication of the pond, which would have negative recreational and ecological effects.
- Avulsion into Round Pond would not only have negative consequences for the future stability of this system, it would also have unpredictable ecological effects on this unique and relatively unspoiled pond system.
- Additionally, there is a substantial risk to the municipal well, which may require the Town of Epsom to relocate or raise the well.

To minimize this risk, removal of the "new" sediment is recommended to restore the "bankfull" channel – *i.e.*, the proper channel capacity. Some potential impacts of this action are:

- There would be short-term impacts to adjacent property owners during the sediment removal operation, since the work would need to be staged from dry ground directly adjacent to the river.
- Depending on the needs of the adjacent landowners, some of the sediment dredged from the channel might be spread out on adjacent property, which would reduce the cost of the action.
- There would be short-term impacts on the recreational use of the downstream beach as well as potential habitat impacts from increased turbidity during dredging.

The total cost of Alternative 2 is approximately $1.3 million. (This does not include the potential modification of the railroad grade, which cannot be determined until the scope for the modification is better defined during final design.)

D.3 Alternative 3 – Stabilize the New Channel

In addition to likely continued headcutting above the avulsion site, as well as the potential for further avulsion of the river downstream, the New Channel formed as a result of the avulsion will continue to adjust its highly erodible boundaries (sand/fine gravel) until a new self-maintaining form (pattern, dimension and profile) is achieved.

Two geomorphic assessment tools, the Channel Evolution Model (CEM) as developed by Schumm, Harvey and Watson in 1984, and Dave Rosgen's Stream Classification System, can provide the user with an understanding of existing conditions as well as potential for natural recovery and/or restoration. Using these tools, the following conclusions were reached:

- Application of the CEM to field observations made by the VHB Assessment Team indicate that the New Channel is exhibiting late Stage III (Widening) and early Stage IV (Stabilizing) tendencies as defined by the CEM.
- The New Channel has several features that suggest that it is evolving to a stable form.
- Floodplain features, however, are inconsistent and not well defined along the newly formed corridor, since the river has not had ample time to develop such features.
- The measurements taken in the New Channel indicate that the New Channel is an "F5" stream type. "F" streams are inherently unstable due primarily to low entrenchment ratios, meaning they are not well connected to their floodplain.
- While "F5" stream types are inherently unstable, they also typically evolve toward a more stable "C5" configuration.
- It is impossible to predict the length of time that would elapse before with certainty because that is determined largely by the frequency and type of flow events. However, we suggest that the time would be on the order of decades.

Appropriate human intervention could serve to accelerate the natural process of channel formation in the New Channel reach. Specifically, under Alternative 3, the existing valley materials would be graded to provide connectivity with an adequate floodplain and to set the stage for relatively rapid development of appropriate bankfull channel characteristics. Some of the more important considerations relating to this measure are as follows:

- The required grading would be relatively easy and inexpensive since most of the work could be performed in the dry and the valley materials should be easy to manipulate to achieve the intended results.

- There would be short-term impacts to adjacent property owners during channel construction operation, since the work would need to be staged from dry ground directly adjacent to the river.
- There could be short-term impacts on the recreational use of the downstream beach as well as potential habitat impacts from increased turbidity during dredging.

The total cost of Alternative 3, including up to nine (9) cross-vanes and the downstream restoration of a bankfull channel, is estimated to be $1.8 to $2.1 million. (This does not include the potential modification of the railroad grade, which cannot be determined until the scope for the modification is better defined during final design.)

D.4 Alternative 4 – Divert the River to its Old Channel

While some within the community have expressed a preference to return the river to its former channel, there are many reasons why this alternative is quite challenging. The main reason relates to the location of the avulsion, and the size of the berm that was destroyed during the avulsion. Replacing that massive berm involves no less than construction of a large, highly engineered dam structure. A Class B diversion dam—even if replacing a natural river bank—is not a simple proposition. Construction of a diversion structure will require that an owner (say, the Town of Epsom) commit to long term monitoring, inspection, maintenance, repair, registration and emergency action plan updates. Given the high profile avulsion that occurred at the site, any proposed structure would likely receive public and agency scrutiny.

Some of the key issues associated with this alternative are as follows:

- Alternative 4 would be the most expensive of the alternatives, and is expected to cost between $4.0 and $5.5 million. (This does not include the potential modification of the railroad grade, which cannot be determined until the scope for the modification is better defined during final design.)
- Alternative 4 is the only alternative that creates new infrastructure that would require on-going inspection and maintenance. It is unclear who would take on this responsibility.
- Any proposal to construct a dam would have to meet the legal standard contained in RSA 482:9, V that states that the NHDES "shall not permit the construction…of any significant hazard potential...dam unless…the dam provides a public benefit...." It is unclear at this time whether a diversion dam at either the upstream or the avulsion site would meet this regulatory requirement.

- The diversion dam's probable classification as a significant hazard (Class B) structure has several important implications, as follows:
  - The structure will be required to meet minimum factors of safety for one-half of the Probable Maximum Flood (PMF), which may greatly exceed the 100-year flood.
  - The structure will need to be inspected at least once every four (4) years. (This requirement may soon be increased to once every two years.)
  - The diversion dam will need to be designed by a professional engineer with at least five years of experience in the design of dams, with the site investigations, calculations and design reviewed by the NHDES Dam Bureau.
  - An Emergency Action Plan (EAP) will have to be prepared for the structure including inundation maps, notification procedures and the "responsibilities of individuals and agencies."
  - Every four years a "test of the Emergency Communication Network" will have to be performed, with continuous updating of the EAP.
  - The structure will be subject to annual registration with the NHDES, including an annual fee of $750 per year for a significant hazard dam.
- Alternative 4 would benefit the property owners along the Old Channel who have become accustomed to the river and enjoy its scenic and recreational values. Similarly, property owners upstream would see the return of the river raised to its former level as a result of the return of the impoundment.
- It might be assumed that Alternative 4 would allow for the reclamation of Cutter's Pit. However, given the extent of the downcutting in the gravel pit that followed the avulsion, it seems likely that the bottom of the New Channel is low enough to have intercepted the water table. Thus, it is unclear whether there is any advantage to this landowner in restoring the river to its former channel.
- Alternative 4A, which is included because the site may be more appropriate geologically, includes construction of a bypass channel through an area currently occupied by a mature white pine *(Pinus strobus)* forest. While this community type is one of the most common in New Hampshire, it would represent a potentially significant impact to upland wildlife resources.

D.5 Relative Costs of Each Alternative

Order-of-magnitude conceptual cost estimates were developed to allow for comparison among alternatives. Because these estimates are based on very preliminary concepts, there is a relatively high degree of uncertainty in their accuracy. However, the relative values among the alternatives provide a reasonable basis for comparisons. All of the cost opinions should be considered approximate, since actual site conditions (such as ongoing erosion of the river bed) may drive up costs further. The geology at the avulsion site is considered to be especially challenging, with the glacial till and marine sediments meeting a deeply plunging bedrock outcrop.

Table ES-1 contains a summary of the cost estimates. It is important to note that, although there are no direct costs associated with the No Action Alternative, there is a high probability of future costs in the form of property damage which is not accounted for in this analysis.

Table ES-1
Preliminary Conceptual Opinions of Cost

Alternative	Estimated Cost
Alternative 1 – No Action	**$0**
Alternative 2 – Strategic Treatment	
Nine (9) cross-vanes	$350-450,000
Dredge 32,000 cu yds (5,000 lin ft)	$500,000
Remove and dispose of spoils (5 miles)	$325,000
Total	**$1,275,000**
Alternative 3 – Alternative 2 plus Restore New Channel	
Nine (9) cross-vanes	$350-450,000
Dredge 32,000 cu yds (5,000 lin ft)	$500,000
Remove and dispose of spoil (5 miles)	$325,000
New Channel Restoration	$500-750,000
Total	**$1.8- $2.1 million**
Alternative 4A – Bypass Channel	
Nine (9) cross-vanes	$350-450,000
Diversion Dam	$3.8 million
Dredge 32,000 cu yds (5,000 lin ft)	$0.5 million
Remove and dispose of spoil (5 miles)	$0.3 million
Dredge Bypass Channel	$0.4 million
Total	**$5.5 million**
Alternative 4B – Restore Avulsion Site	
Nine (9) cross-vanes	$350-450,000
Diversion Dam	$2.7 million
Dredge 32,000 cu yds (5,000 lin ft)	$0.5 million
Remove and dispose of spoil (5 miles)	$0.3 million
Total	**$4.0 million**

Notes: Diversion Dam cost estimates by Kleinschmidt Associates. Remaining items estimated by VHB. Costs do not include work needed to modify the railroad grade to the east of the river, which is included in Alts 2, 3 and 4, but which cannot be accurately defined at this time.

E. Summary of Key Findings

Below, we summarize the key findings and recommendations:

Finding 1: The No-Action Alternative should be rejected. We draw this conclusion primarily due to the substantial risk of further property and ecological damage that would result from continued headcutting above the avulsion and in the Little Suncook River and in Leighton Brook, and the potential for a secondary avulsion downstream.

Finding 2: All of the measures contained in Alternative 2 are important to minimize the risk of further damage. Since there is substantial risk of further property and ecological damage, some specific actions should be taken as soon as possible to help manage this risk. The measures included in Alternative 2 will require further evaluation a design during a subsequent project development phase, but are thought to be relatively safe and cost effective ways to meet the project goal.

Finding 3: The most effective way to minimize the potential to future property impacts is to implement Alternative 3. Implementation of Restoration Alternative 3 would restore the "New Channel" corridor to an equilibrium form, and hence, minimize the production of sediment from about 2,500 linear feet of channel. This would be accomplished by creating a "C5" stream type with sufficient floodplain to move the river toward a stable equilibrium endpoint.

Finding 4: Returning the river to its former channel through implementation of Alternative 4 is not the most cost effective way to minimize the chance of further property damage. Some in Epsom and in the downstream communities of Pembroke and Allenstown have called for action to return the river to its former course, with the concern that the avulsion is the cause of the recent extensive flood damage. However, the relationship between the flooding and the avulsion is probably not as strong as perceived. Our review of the river leads us to conclude that such an expensive and difficult course of action is probably not the most prudent action.

Finding 5: Regardless of the specific alternative chosen, proper design and construction is necessary to ensure project success. Rivers are complicated, and the final design of the structures will take time. Proper installation of the grade stabilization/ habitat structures (e.g., cross-vanes) in accordance with final design and construction documents will minimize future maintenance needs and maximize potential for long-term stability.

Finding 6: Additional studies and engineering will be required to arrive at a plan that can be properly built. While a great deal of survey has been completed or is in progress, it should be noted that additional ground survey will be required to allow for final design. Additionally, geotechnical explorations and HEC-RAS modeling will need to be completed prior to or during final design. The design for any of the alternatives can be expected to take at least one year. Alternative 4 would likely take two to four years to design and permit.

Finding 7: The design for the selected alternative should be assessed based on the findings of two related studies that are currently in progress on the Suncook River. The USGS is re-mapping the floodplains along the river and modeling sediment transport in light of the avulsion. FEMA has funded a study of how dams on the river might affect flooding. Since the findings and recommendations of these two related studies are not available at this time, the design of the selected alternative should be reviewed once available.

Finding 8: A post-construction monitoring and maintenance plan should be an integral part of the project. Proper design and installation will minimize the magnitude and frequency of any future maintenance requirements, but the first two to three years following construction are typically the most vulnerable years for channel and structure performance. Therefore, a short-term monitoring program, with provisions and funding for adaptive management if necessary should be included in the construction/implementation plan for the selected alternative.

1

Geomorphic Assessment

1.1 Introduction

An extreme rain event occurred on May 15 and 16th 2006 in New Hampshire which resulted in a state-wide flood. The Suncook River, which flows south-west towards the Merrimack River from its headwaters in Crystal Lake, experienced a 100-year flood event at this time. The high flood waters resulted in an avulsion just south of the Town of Epsom upstream of Bear Island (**Figures 1-1** and **1-2**). Just west of the avulsion site, the Suncook formerly split into two channels at the Huckins Mill Site: a primary (west) channel and a smaller, secondary (east) channel forming Bear Island. As a result of the 2006 avulsion, the Suncook River now flows through a gravel pit to the northeast of Bear Island before rejoining a portion of a pre-existing secondary channel that formed the eastern margin of Bear Island. Nearly two miles of former channel now lays abandoned, including 1.5 miles of the primary channel that formed the western margin of Bear Island. Aside from small pools and seeps, and contribution from a small tributary, the abandoned portions of the Suncook are not expected to maintain significant year-round flow. The new channel is approximately 1.0 miles long; of which 0.44 miles is newly eroded valley.

A team of engineers and scientists (from the consulting firms VHB/Vanasse Hangen Brustlin, Inc., Parish Geomorphic, and Kleinschmidt Associates), was hired by the Town of Epsom with funding provided by the NH Department of Environmental Services to complete an assessment of the project area upstream and downstream of the avulsion. The team included several highly experienced individuals who specialize in "fluvial geomorphology," the science dedicated to understanding rivers and stream and the processes that form them. The team also included river engineers, who are responsible for developing the conceptual designs of alternatives intended to address the stability and flooding problems related to the avulsion.

The overall goal for this study is to provide sufficient information to the community (including property owners as well as local, state and federal stakeholders) to allow an informed decision as to what course of action should be followed to prevent further impacts to private property, ecological resources, and water quality. This goal will be met when a restoration plan is produced that recommends a preferred alternative to either return river to historical channels or work with existing channel to find a stable endpoint that minimizes potential future damage to infrastructure and eliminates water quality impairments.

This chapter presents the results of the assessment, including a background review, desktop analysis, hydrologic assessment, detailed fluvial geomorphological survey and analysis. The geomorphic assessment is a tool for developing recommendations for the restoration and/or stabilization of the avulsion site.

Appendix A includes representative photographs taken during the field work. **Appendix B** includes a summary of the hydraulic and geomorphic parameters measured in the field, while **Appendix C** contains additional geomorphic interpretation of the data (developed by Parish Geomorphic). **Appendix D** contains the observations of Dr. Chad Whittkop, who has been collecting data on the avulsion site since the May 2006 flood event.

1.2 Background Review

Several documents were at our disposal for background information regarding the Suncook River and the May 2006 avulsion. A summary of these reports will be briefly described below.

Inter-department communication from the State of New Hampshire (Wittkop, 2006) was reviewed. This memo contained the basic information about the events leading up to the avulsion, the field data acquired and details regarding the old and new channel paths. The new channel was approximately 1.03 miles long whereas the old path was 1.52 miles long. This shortening increased the gradient of the channel by 44 percent. The avulsion eroded through finer material than was present in the old channel and added approximately 150,000 cubic yards of sediment to the Suncook River in both the channel and on the floodplain. A large quantity of this sediment was deposited downstream of the avulsion in places deposits were up to five feet thick. Significant damage was done to nearby property through flooding and sediment deposition in the over bank zone. The increase in bed elevation could pose future problems with respect to flood water elevations.

Wittkop *et al.* (2007) produced a field guide (*Geology of the May 2006 Suncook River Avulsion)* detailing observations made of the Suncook River following the May 2006 avulsion. A GIS analysis was completed to establish the mechanisms for the initiation of the new channel. The analysis determined that pooling water in the gravel pit reached an elevation high enough to overflow onto an access road which acted as a spillway. The river then eroded away downstream and proceeded to erode in a headward direction.

Wittkop (2007, 2008) provided further long-term observations for the Suncook River to outlining observations from field visits in March and July 2007. Wittkop notes significant amounts of lateral erosion in the new channel, particularly between March and July 2007. Significant incision is also noted in the new channel where a wetland had previously existed. This had resulted in significant headcutting and bank failures as far as 2,500 ft upstream. Significant deposition was also noted downstream of Bear Island and upstream of Short Falls.

Finally, we reviewed an undergraduate thesis from MIT entitled *Mechanisms governing avulsions in transient landscapes: Analysis of the May 2006 Suncook River Avulsion in Epsom, New Hampshire* (Perignon, 2007). The thesis described the events leading up to the May 2006 flood including the weather and geologic setting of the river. Perignon also reconstructed the flood history of the Suncook River using old gauging information for the Suncook and proxy discharge information from a nearby river, the Soucook River. Based on this information, the flood frequency was determined for the Suncook. Through this analysis it was determined that the May 2006 event was a 100-year flood event. Perignon (2007) also determined the mechanism for the avulsion which was a combination of geology, flood level, Cutter's Pit, and the effect of the downstream dams on the surface water energy gradient.

1.3 Desktop Analysis

A desktop analysis of was conducted to identify factors responsible for the present state of the watercourses within the Suncook River study area, and included historical changes that may have occurred which influenced the morphology of the river. This review was also used to delineate study reaches for further evaluation. Information reviewed included available topographic mapping, geologic mapping, and aerial photographs. Historical analyses provided insight on the degree of natural fluvial activity and human impacts on the river. A sequence of aerial photographs for the years 1953, 2003, 2006, and 2007 were used for the assessment.[1] We also reviewed historic USGS topographic maps from 1921 and 1957.

---

[1] Our search did not find aerials older than the 1953 flight, even though aerials taken in the 1940s are available for some portions of NH.

1.3.1 Historic Land Use

Historic changes in land use are examined to determine if changes in land management are the causes for changes observed in the channel. Aerial photographs from 1953 and 2003, as well as the USGS maps from 1921 and 1953, were used to determine if the avulsion of May 2006 was influenced my any major land use changes. Information from both of these sources indicates that, overall, there was an increase in forested areas and an increase in houses and other buildings. North of US 4, the land was primarily agricultural with some forested lands to the west in 1953. The 2003 photographs show an increase in forested lands and a larger number of houses. South of US 4 the land use was primarily forested land and scrub land. By 2003, the amount of forested area had increased as had the number of buildings near US 4. Moreover the area was now a gravel/sand pit north-east of Bear Island which is where the avulsion occurred. The land around and on Bear Island consisted mainly of scrub land and forested land in 1953 with farm land to the east of the secondary channel. The 2003 aerial photographs show an increase in forested land and a slight decrease in the area of agricultural land to the east of the secondary channel. South of Bear Island the land use was agricultural lands and forested lands. There was no change in land use in this area between the 1953 and 2003 aerial photographs. The land surrounding the large meanders downstream of Bear Island consisted primarily of agriculture and small areas of forested land in 1953. The 2003 aerial photographs showed an increase in forested area surrounding the river. In 1953, the land surrounding the downstream bridge consisted primarily of forested area and agricultural area. By 2003 the air photos showed an increase in the forested area surrounding the water course.

The 1921 topographic map confirms that little changed in the watershed between 1921 and 1953, although an increase in forested cover can be noted. The 1921 map confirms that the two Huckins Mill Dams were in place at that time. They also indicate that a third dam was in place on the Old Primary Channel in 1921 which has since been abandoned. This dam was located approximately 2,200 ft downstream of the current Huckins Mill Dam. No other large-scale changes in the river were present, although it must be noted that the methods used to compile these older USGS maps were approximate relative to the standards used for the 1953 maps. Thus, fine scale changes would not necessarily be apparent from this review.

Overall, the historic aerials and topographic maps indicate that there has been an improvement in the hydrological condition of the watershed over the past 50 years with respect to land use changes. An increase in forested area typically leads to greater retention of rainfall in the upper watersheds which decreases the propensity for runoff and flooding in the watershed.

1.3.2 Migration Rates

Rivers are dynamic systems that move across their flood plain through the growth and evolution of meanders. Meanders can migrate both laterally and in the downstream direction. The migration rate is defined by the distance a meander bend can erode over the period of a year. This rate is generally calculated using historic aerial photographs at least 50 years apart. For this study, aerial photographs of the Epsom area were obtained for 1953 and 2003. Migration rates were calculated for five different meanders. For three of these meanders, no change in the location of the meander bend could be measured (i.e., migration rates were negligible). Southward migration of two of the meanders downstream of Bear Island (above Short Falls Road) was measured at approximately six (6) feet between 1953 and 2003, essentially at the limit at which aerial photography can reliably measure such migration. The meanders used for migration rates are illustrated in **Figure 1-3**.

The planform of the Suncook River was historically very stable prior to the 2006 avulsion event. In contrast, the newly avulsed channel cut through non-cohesive and easily erodible material and has continued to dramatically adjust planform since the avulsion event. A comparison of channel locations immediately following the avulsion event in 2006 and after the spring floods of 2007 was completed. **Figure 1-4** shows the location of the Suncook River in 2006 (including the abandoned channels) as well as the location of the river in 2007. The planform of the newly avulsed channel has changed considerably in the year following the avulsion. The most prominent meander has migrated around 140 to 150 feet in the downstream direction. Whittkop (2008) reports similar observations based on aerial photo interpretation as well as GPS data in 2006 and 2007. The migration highlights the continued adjustment and instability at the avulsion site and in the New Channel.

1.3.3 Meander Belt Width

Meander belt width delineation determines the corridor within which the river migrates back and forth across its floodplain. This is typically an important consideration when land use near the watercourse is changing as it can help steer planning to minimize impacts to infrastructure, property, and the long-term stability of the river. Meander belt width is often an important consideration in the sizing of bridge spans and road crossings. For the purposes of this study, the belt width delineation will be used to assist the VHB team and DES in evaluating the risks of restoration options that allow the channel to adjust to stabile conditions over time and on its own. The belt width delineation will establish a corridor that bounds future planform adjustment through the project site.

The meander belt width was determined to be approximately 1,040 feet. The width of the meander belt was determined by measuring the amplitude of the largest meander and applying this width to delineate belt width around the centerline of the valley. Due to the recent change in course of the river, the meander belt width was delineated for several hundred meters up and downstream as the geology was similar to best represent possible future migration of the Suncook.

1.3.4 Reach Delineation

The Suncook River was divided into reaches for comparison and discussion. Typically, reaches are delineated based on geomorphic similarity as identified by desktop measurements of channel sinuosity, gradient, valley form, geology and degree of valley confinement. The complexity of the Suncook project site and severe departure from pre-avulsion conditions necessitated that sites were selected based on river segments whose distinction added to our discussion and understanding of the changes to the project area after the avulsion in 2006. The reaches are summarized below and shown overlain the 2006 aerial photo in **Figure 1-2.**

- *The New Channel:* The new channel formed as a result of the avulsion. This site is the channel that cut from upstream of the quarry to the old secondary channel of the Suncook.
- *The Old Primary Channel:* The historic primary channel prior to the avulsion which flows to the west of Bear Island and includes the Mill dam site.
- *The Old Side Channel:* The historic side channel originating just above the Mill dam site which flows to the east of Bear Island.
- *The Confluence Area:* The channel just downstream of where the New Channel and the Old Primary Channel converge into a single channel.
- *Short Falls Area:* The channel in the vicinity of the Town Park located just downstream of the Short Falls Road Bridge.

We also studied a "Reference Reach," which is defined as a river segment that represents a stable channel within a particular valley morphology. The character of a reference reach can be used to extrapolate to disturbed or unstable reaches in similar valley types for the purposes of geomorphic analysis. For this study, we chose an area of the Suncook River upstream of Epsom. It was selected as the first site upstream of the area affected by the avulsion that was suitable as a reference location.[2]

---

[2] Generally, a reference reach should be in a natural condition, free from anthropogenic disturbance, and at an equilibrium condition. Further discussion on the data collected from the Reference Reach is provided below. It should be noted that an ideal reference reach could not be located. That is, the Reference Reach measured and reported in this study appears to have been modified by past alterations. Thus, while it should serve as an adequate reference for hydrological and hydraulic purposes, interpretation of geomorphological data from the Reference Reach must be done with some caution.

1.4 Hydrology

Hydrology for the project was completed to lend context to our assessment and for further use during the development of the conceptual restoration alternatives.

1.4.1 Statistical Hydrology

The Suncook River begins at Crystal Lake in the southeastern part of New Hampshire and drains into the Merrimack River. The Suncook River is about 39 miles in length with a total drainage area of 256 square miles. Peak discharges in the system seemed to occur from early March to late May with the spring thaws (Perignon, 2007). The USGS stream gage at North Chichester has a drainage area of 157 square miles and was located approximately 2.5 miles upstream from the project site. The period of record for the gauge was from 1918 to 1970. After review of all the data it was determined that the data could be considered representative of the more recent hydrology. Given the data gaps in other nearby gages, and the uncertainties with prorating flow from other watersheds, a record extension of the Suncook data did not seem necessary or reasonable. A log-Pearson Type III analysis of the gauge data resulted in similar results as published by the USGS.

Flows were proportioned by straight drainage area to develop flow frequency data for the study reach. This is a conservative method, since flood flows are often prorated at slightly less than a straight ratio. However, there was no further information in the flood insurance studies or way to calculate this independently, so any coefficient would be arbitrary. The drainage area of the study reach is between 206.5 square miles ("Below Little Suncook River") and 224.6 square miles ("Above Bear Brook," which is near the Epsom/Allenstown line). **Table 1-1** summarizes the results of the statistical hydrology analysis.

Flow duration data was also generated from the gage data at North Chichester and translated to the project site. **Table 1-2** summarizes the results of the flow duration analysis for key months (seasonal and annual high and low months).

1.4.2 Huckins Mill Dams and Historic Flooding

The two dams at the Huckins Mill Site impounded 31 acres which extended upstream of the avulsion site. The dams regulated flows down the Old Primary Channel and the Old Side Channel. The 1978 FEMA Flood Insurance Study and dam records show both dams at the same elevation of 329 feet. The dam heights are 5 feet and 13 feet, and the widths are 85 feet and 90 feet for the Old Side Channel and the Old Primary Channel, respectively. The dams were originally built in the late 19th century and reconstructed after the flood in 1936.

Table 1-1
Suncook River Flow-Frequency Summary near Epsom, New Hampshire

Return Interval	At Streamgage[1] Q (cfs)	Above Little Suncook River Q (cfs)	Below Little Suncook River Q (cfs)	Above Bear Brook Q (cfs)
2-Year Flood	2,220	2,340	2,920	3,180
5-Year Flood	3,480	3,680	4,580	4,980
10-Year Flood	4,510	4,760	5,930	6,450
25-Year Flood	6,060	6,400	7,970	8,670
50-Year Flood	7,420	7,840	9,760	10,610
May 2006 Flood	7,600	8,030	10,000	10,870
100-Year Flood	8,970	9,470	11,800	12,830
March 1936 Flood	12,900	13,600	17,000	18,500
500-Year Flood	13,400	14,200	17,600	19,200

Notes:

1 Data are from Olson (2007), *Flood of May 2006 in New Hampshire*, U.S. Geological Survey Open-File Report 2007-1122.

Table 1-2
Annual and Monthly Flow Duration Analysis for Key Periods, Suncook River

	At Streamgage[1] Q (cfs)	Above Little Suncook River Q (cfs)	Below Little Suncook River Q (cfs)	Above Bear Brook Q (cfs)
Annual Mean	235	248	309	336
Annual Median	126	133	166	180
Annual 90% Exceedance	19	20	25	27
Annual 10% Exceedance	580	613	763	830
February Mean (Winter Low Flow)	214	226	282	307
February Median	150	158	197	215
February 90% Exceedance	300	317	395	429
February 10% Exceedance	154	163	203	220
April Mean (Annual High Flow)	737	778	969	1,054
April Median	608	642	800	870
April 90% Exceedance	255	269	335	365
April 10% Exceedance	1,400	1,478	1,841	2,003
August Mean (Annual Low Flow)	49	52	65	70
August Median	33	35	43	47
August 90% Exceedance	11	12	14	16
August 10% Exceedance	102	108	134	146

Notes:

1 Hydrological analysis provided by Kleinschmidt Associates.
2 The 90% Exceedance value represents the flow that is that is rarely exceeded (only about a 1 in 10 chance) in a particular time period.
3 The 10% Exceedance value represents the flow that is usually exceeded (about 9 out of 10 times) in a particular time period.

The May 2006 flood was well above a 50-year flood; however, it was of considerably smaller magnitude than a flood that occurred March 1936 which did not result in an avulsion. The dams on the primary and side channels failed during the March 1936 flood, this may be why there was no avulsion at this time (Perignon, 2007). During the May 2006 flood the dams held, which created a back water effect not experienced during the 1936 flood, this was a contributing factor in the May 2006 avulsion.

Note that the Huckins Mill Dams create a narrow impoundment at approximately elev. 329 ft. which, under normal flow conditions, extends approximately 2.1 miles upstream (see **Figure 1-5**). One consequence of the avulsion is that the river now bypasses the Huckins Mill Dams, which has effectively eliminated the impoundment.

Landowners have commented that the character of the river upstream of US 4 has changed significantly from pre-avulsion conditions, with the river becoming shallower than in the past, and with a discernable flow in reaches were there was previously very little to no current (e.g., Peter Arvanitis, personal communication, March 26, 2008). Additionally, the water surface elevation in oxbow ponds directly adjacent to the river has also dropped considerably. These observations are entirely consistent with the expected changes that would result from the removal of the Huckins Mill Dams as the primary control on the water surface elevation upstream of the dam.

Since the dams are "run-of-the-river," the degree to which they act as a hydraulic control can be expected to diminish significantly as the flow increases. That is, the most perceivable changes in volume and surface area would typically be for low flows. For higher flows, (generally at and above the normal spring flow), the effect of the bypassing of the dam should be relatively less significant throughout the reach. A similar prediction can be made for velocities in the now free-flowing reaches.

The elimination of an impoundment on a previously free-flowing river would typically have a number of beneficial ecological effects. However, the changes have also brought about impacts to the recreational use of the impoundment. These issues are further discussed in Chapter 3.

1.4.3 Historic Railroad Grade and Flood Elevations

One significant man-made feature in the study area is the railroad grade that runs parallel to the river on the eastern side of the valley. The railroad, known as the Suncook Valley Branch of the Boston & Maine Railroad, is depicted as an active line on historical maps dated 1921, but is not shown on similar maps from

1957, suggesting that the rail line may have been abandoned between those dates.

The railroad grade clearly impacts the floodplain of the Suncook. **Figures 1-6** and **1-7** illustrate the location of the railroad relative to a reach of the river between US 4 and the avulsion site. Note that, at least in certain areas, the grade appears to act as a lateral dike, preventing rising flood flows from dispersing across the floodplain. (See cross-sections A-A and B-B.) Only at the height of the 100-year flood would the Suncook River water surface overtop the railroad grade and spill into the portion of the floodplain to the east of the grade. The effect of this would be to increase flood elevations and velocities as the flood stage increases to the 100-year elevation. The impact of the dike on the stability and function of the main river channel and floodplain should be addressed during the final design phase through application of an appropriate water surface profile model such as HEC-RAS. If the hydraulic analysis indicates that the dike has a significant negative impact on river and/or floodplain function, then removal or modification of the dike should be explored.

1.5 Field Reconnaissance

Field reconnaissance of the Suncook River study area began with two visits, one in March 2007 and a second in July of 2007. The initial reconnaissance was conducted of the study area to allow better familiarization of the watershed, to further identify problem reaches or reaches in need of assessment and restoration, to refine the reach delineation and to verify any factors related to the present morphology of the channels within the watershed. Following the initial field reconnaissance, Parish and VHB staff completed intensive geomorphic surveys in order to assess the existing cross-sectional geometry, planform, channel profile, substrate and bank characteristics of the reaches within the project area.

1.5.1 Site Selection

After completion of reach delineation and initial reconnaissance, specific sites within the project area were chosen for geomorphic surveys. The goals of the project and the need to collect sufficient information in a very large and complicated project area were carefully reconciled with the scope of work and the project budget to determine the frequency and detail of the geomorphic surveys. It was decided that full detailed sites (see subsequent section, Field methods) were to be collected in four of the most complex and important reaches, and a more basic cross-section survey would be completed in the remaining two reaches. **Table 1-3** summarizes the work completed in each reach.

Appendix B provides a summary of data and measurements along with cross-sections plots of the survey sites.

Table 1-3
Summary of Data Collected for Each Reach

Location	Works Completed
New Channel	Ten detailed and monumented cross-sections Thalweg and Bankfull profile survey Bank descriptions, height, angle, material description, in-situ shear stress, rooting depth Modified Wolman pebble count of bed substrate Photographs
Old Primary Channel	Six detailed and monumented cross-sections Thalweg and Bankfull profile survey Bank descriptions, height, angle, material description, in-situ shear stress, rooting depth Modified Wolman pebble count of bed substrate Photographs
Old Side Channel	One detailed and monumented cross-sections Bank descriptions, height, angle, material description, in-situ shear stress, rooting depth Modified Wolman pebble count of bed substrate Photographs
Confluence Area	Nine detailed and monumented cross-sections Thalweg and Bankfull profile survey Bank descriptions, height, angle, material description, in-situ shear stress, rooting depth Modified Wolman pebble count of bed substrate Photographs
Short Falls Area	Two detailed and monumented cross-sections[1] Bank descriptions, height, angle, material description, in-situ shear stress, rooting depth Modified Wolman pebble count of bed substrate Photographs
Reference Reach	Five detailed and monumented cross-sections Thalweg and Bankfull profile survey Bank descriptions, height, angle, material description, in-situ shear stress, rooting depth Photographs

Note:
1 Additional surveyed cross-sections in the Short Falls area (also the location of the Epsom Town Beach) were supplied by the USGS following field work.

1.5.2 Field Methods

Detailed field sites included measurements of channel and bank characteristics and bankfull flow conditions. At each of the detailed sites, cross-sections were measured at five to ten locations, including pools, riffles and transitional areas. At each cross-section, bankfull width and depth, entrenchment, as well as low flow dimensions were recorded. Substrate was sampled using a modified Wolman pebble count. Sub-pavement was also characterized where appropriate. Bank assessment included measurements of height, angle, bank composition, *in-situ* shear strength, vegetation and rooting depth. Channel thalweg and bankfull profile surveys were completed at the detailed sites. All work was consistent with the Site Specific Project Plan submitted in August of 2007.

Bankfull channel dimensions could not be obtained in the New Channel due to this channel having been newly created by the May 2006 Flood event and subject to a second sizable spring flood in April 2007, which caused considerable channel adjustment. Therefore, insufficient time or bankfull flow conditions have occurred to form identifiable indicators.

1.5.3 Results of Field Work

In this section a summary of data collected from the field reconnaissance is presented for comparative purposes. Interpretation of the data and further geomorphic and engineering analysis is discussed in subsequent sections of this report.

1.5.3.1 Cross-sections

The natural sizes of channels are such that the channel capacity is approximately that of the "bankfull" flow. A primary assessment tool is to identify this feature and evaluate the resulting hydraulic geometry and hydraulic flow conditions. This evaluation will give insight to the state and condition of the river. An oversized channel lacks the stream power to transport the sediment delivered to it and therefore aggrades. An undersized channel is highly unstable and tends to widen and/or become entrenched. It is therefore important that a channel have the appropriate geometry and slope to properly balance erosive and depositional forces if it is to function like a naturally stable stream. The channel geometry will influence the channel type, incision and entrenchment ratios, and give insight to the stage of adjustment and evolution of the reach. A summary of the existing cross-section geomorphic relations is presented in **Table 1-4**.

Bankfull channel dimensions were not identifiable in the New Channel as the channel was newly formed and actively adjusting. However bankfull discharges were interpolated for the reach using upstream and downstream estimates.

Hydraulic geometry values in **Table 1-4** and in **Appendix C** for the New Channel were determined by stage discharge relationships developed at each cross-section.

Table 1-4
Existing Conditions: Bankfull Cross-sections

	New Channel	Old Primary Channel	Old Side Channel	Confluence Area	Short Falls Area	Reference Reach
Bankfull Width (ft)	129.73	91.14	57.42	102.4	163.70	91.87
Bankfull Depth (ft)	2.95	2.86	4.80	3.15	14.23	4.74
W/D Ratio	47.27	32.56	11.96	127.30	11.50	23.30
Entrenchment (ft)	173.3	135.15	344	132.28	100.00	136.49
Entrenchment Ratio	1.36	1.51	6.0	1.30	1.24	1.49

1.5.3.2 Profile and Planform

Planform characteristics are determined during the desktop assessment by reviewing the aerial photographs and topographic maps of the project area (see Section 1.3 - Desktop Analysis). The data is presented here because planform information is often utilized when assessing data such as profile and cross-section information, which comes from the geomorphic surveys. Planform and grade characteristics are used in channel typing, stability analysis, and sediment transport calculations. **Table 1-5** shows average values for geomorphic profile and planform metrics for the conditions at the time of the field survey.

Table 1-5
Existing Conditions: Planform Characteristics

Reach	New Channel	Old Primary Channel	Old Side Channel	Confluence Area	Short Falls Area	Reference Reach
Gross Channel Grade (ft/ft)	0.18 %	0.36 %	0.40 %	0.30 %	1.40 %	0.60 %
Sinuosity	1.17	1.10	1.29	1.03	1.14	1.06

1.5.3.3 Substrate

Bed material was sampled at each cross-section during the field assessment using a modified Wolman Pebble Count. **Table 1-6** shows cumulative percent finer values for a combination of all pebble counts completed in each reach.

Table 1-6
Existing Conditions: Channel Bed Sediment Gradations

Reach	New Channel	Old Primary Channel	Old Side Channel	Confluence Area	Short Falls Area[1]	Reference Reach[1]
D100 (mm)	1020	2047	2048	1024	1024	2047
D95 (mm)	260	500	1024	96	260	500
D84 (mm)	60	400	255	32	60	400
D50 (mm)	1.90	127.90	48	1	1.90	127.90
D35 (mm)	0.20	47.90	15.90	.20	0.20	47.90
D16 (mm)	0.002	0.049	1.90	0.009	0.002	0.005

Notes:
1 Assumed gradation of Old Primary Channel based on field observation.

1.6 Geomorphic Analysis

1.6.1 Bankfull Discharge

An empirical analysis of cross-section and slope data collected during the field assessment was used to estimate the bankfull hydrology for the project. Empirical equations that utilize channel dimensions, slope and some form of resistance to provide an estimate of the flow in a natural channel, these were used to estimate bankfull discharge. Equations used include, Manning's and Darcy Weisbach with the friction factors n or f (or 1/√f) estimated by Cowan, Strickler, Leopold, Wolman and Miller, Limerinos, Bray, Griffiths and others. Not all surveyed cross-sections were used in the analysis. Generally, the riffle and run cross-sections that best represent the site with clear bankfull indicators are used to calculate the bankfull characteristics. **Table 1-7** summarizes the results of the bankfull hydrologic assessment and presents bankfull discharge estimates for each reach in the project area. **Appendix B** provides additional details regarding both the hydraulic geometries and the results of the empirical bankfull analysis.

Table 1-7
Bankfull Discharge Estimates, Suncook River

	Empirical Analysis (cfs)			Bankfull
Reach	High	Low	Average	Discharge, CFS
Reference	1,588	837	1,133	1,133
Old Primary	886	451	710	710
Old Side	792	792	792	792
New Channel				1,502
Confluence	2,389	1,487	1,834	1,639
Short Falls	1,183	1,183	1,776	1,776

Source: Parish Geomorphic

Data collected in the New Channel Area could not be used to help determine bankfull discharge. The channel in this reach was newly formed, was still adjusting rapidly and had no established bankfull indicators. Bankfull discharge in this reach was assumed to be equal to the sum of the calculated bankfull discharge in the Old Primary and Old Secondary Channels, since it was these channels that conveyed flows in the place of the New Channel prior to the avulsion in 2006.

Of all the surveyed reaches, the Confluence Area had the greatest variability in channel condition and geometry. The channel ranged from deeply incised between high bars in the upper reaches to aggraded to the elevation of the floodplain in the lower reaches. For these reasons the calculated bankfull discharges are not representative of natural conditions. More reliable bankfull discharge estimates from upstream and downstream of the reach were used to interpolate reasonable bankfull discharges for the Confluence Area.

1.6.2 Regional Curves

A comparison of geomorphic parameters was made with regional hydraulic geometry curves as published in the Guidelines for Natural River Channel Design and Bank Stabilization, NHDDES & NHDOT, 2005. The regional curves predict bankfull discharge, bankfull area, bankfull width, and bankfull depth based on upstream drainage area (**Appendix C**).

Table 1-8 shows the comparison with the regional curve information and the findings of this study. The findings of the study are consistently less than predicted by the regional curves. There are many possible reasons for this discrepancy. It is possible, but not confirmed, that the watershed of the study area may be forested and relatively undeveloped as compared to those used to develop the regional curves. It is also possible that the impact of the avulsion on both the channel shape and the reliability of the bankfull indicators has skewed the findings. Additionally, it is unclear whether bedrock controlled channels are included in the NH Regional Curves (as is the case for the Maine Regional Curves), which would also explain the differences.

While the exact reasons for the difference between the regional curves and the empirical bankfull discharge estimates are unclear, the estimates are reasonable and will allow us to meet the objective of this study: to understand the different alternatives for addressing the stability and flooding issues associated with the May 2006 avulsion. Since our study includes only conceptual designs, rather than a full engineering scope, the actual bankfull discharge value is less important than if we were attempting to provide a final design.

Table 1-8
Comparison of Regional Curve and Study Results

	Drainage Area (sq mi)	Bankfull Discharge (cfs)	Area (sq ft)	Width (ft)	Depth (ft)
Regional Curve Estimates					
Reference Reach	165.8	4,655	760.3	151.9	5.0
New Channel	206.5	5,686	897.4	169.2	5.3
Confluence Area	206.5	5,686	897.4	169.2	5.3
Short Falls Area	210.0	5,774	908.9	170.6	5.3
Study Results					
Reference Reach		1,133	271.2	88.2	3.1
New Channel		1,502	N/A	N/A	N/A
Confluence Area		1,639	333.5	123.8	2.71
Short Falls Area		1,776	1,818	77.9	2.3
Comparison					
Reference Reach		24 %	36 %	58 %	62 %
New Channel		26 %	-	-	-
Confluence Area		29 %	37 %	73 %	51 %
Short Falls Area		31 %	200 %	46 %	43 %

Source: Parish Geomorphic

1.6.3 Sediment Transport

The results of the detailed field work were used to complete an assessment of sediment transport. The collection of detailed field information at four of the project reaches allowed for analyses to be performed based on critical shear stress and permissible velocities in order to identify erosion thresholds. Erosion thresholds determine the magnitude of flows required to potentially erode and transport sediment, and when compared to bankfull conditions they provide an indication of channel stability. **Table 1-9** summarizes the average bankfull hydraulic properties of all cross-sections in each reach that were used to determine bankfull flow conditions. These were typically limited to riffle and run sections with good bankfull indicators.

Critical discharge, defined as the flow required to mobilize the D_{50} particle, can be used to examine sediment transport characteristics of the channel. Channel depth can vary greatly across a cross-section. It is often the case that sediment may be mobilized in one area of the cross-section and not in another. For the purposes of this analysis, the critical discharge is defined as the discharge that mobilizes the D_{50} sized particle over a surface area greater than 50 percent of the bed surface.

Table 1-9
Bankfull Discharge Hydraulic Properties, Suncook River

Reach	New Channel	Old Primary Channel	Old Side Channel	Confluence Area	Short Falls Area	Reference Reach
Bankfull Discharge (cfs)	1,502	710	792	1,639	1,176	1,133
Froude Number	0.69	0.48	0.41	0.53	1.13	0.43
Shear Stress (lbs/sq ft)		0.50	0.75	0.50	1.99	1.11
Average Velocity (ft/s)		2.82	4.2	4.99	9.76	4.30
Shear Velocity (ft/s)		0.50	0.62	0.51	1.01	0.76
Stream Power (lbs/ft-s)		0.02	0.05	0.02	0.25	0.05

Source: Parish Geomorphic

Streams continually adjust their dimensions to accommodate changes in their sediment transport and discharge regimes. As such, thresholds of particle movement and transport will vary spatially and temporally as watercourses adjust to local variations in slope, bed material, discharge and modifying factors. The calculations performed to determine critical discharge for bed materials were based on formulas for permissible velocity (Komar, 1987) and shear stress (Lane, 1955). These methods are well suited for the non-cohesive sediment channels found within the watershed. The Manning's 'n' values provided in the tables were for bankfull conditions and were derived from Limerinos' (1970) equation using average bankfull depth and the D50 for a site. Two different methods were used because of the large variability in sediment between sites. Komar (1987) is considered most appropriate and yields more reliable results when employed for larger sediment sizes (cobbles, boulders etc). Therefore this method was used for the Old Primary Channel and the Reference Reach which generally had cobble sized material. However, the Confluence Area and the New Channel contained considerably finer material and the use of Komar (1987) was not appropriate for these sites therefore the method developed by Lane (1955) was used to determine the erosion thresholds. **Table 1-10** shows the average hydraulic properties at the critical discharge for the reach. Values from **Tables 1-9** and **1-10** can also be used to guide selection of stable bed and bank materials for restoration purposes.

Table 1-10
Critical Discharge Hydraulic Properties, Suncook River

Reach	New Channel	Old Primary Channel	Confluence Area	Reference Reach
D_{50} (mm)	1.90	127.90	1.0	127.90
Critical Discharge (cfs)[1]	1,357	2,094	653	1,951
Ratio: CD/BFD	91%	295%	40%	172%
Maximum Critical Depth (ft)	3.90	4.32	1.47	1.33
Average Critical Depth (ft)	2.78	3.18	1.01	0.97
Max. Critical Velocity (ft/s)	4.92	9.24	2.29	2.80
Ave. Critical Velocity (ft/s)	3.77	5.83	1.57	1.78
Method	Lane (1955)	Komar (1987)	Lane (1955)	Komar (1987)

Insight to the stability of the different reaches can be gleaned from the critical discharge analysis. Critical discharges in the Old Primary Channel and the Reference Site occurred at 295 percent and 172 percent of bankfull discharge, respectively. The high ratio suggests that the bed is stable under high flows, supporting the assertion that these channels remain stable (Reference Site) or were stable before the avulsion (Old Primary Channel).

The critical discharges analysis provides interesting insight to the current condition of the New Channel. The critical discharge is 91 percent of the bankfull discharge estimate for this reach. Again, it is important to remember that the bankfull discharge estimate was not made by assessing channel and slope geometry in the reach, but by interpolating from bankfull discharges upstream and downstream of this reach. The ratio suggests that the bed sediments and existing channel geometry represent conditions that would be expected to remain stable at the bankfull flow of 1,502 cfs. This indicates that the low flow channel geometry in the New Channel may be sized appropriately for long term bed stability. The primary destabilizing factors in the reach are the entrenchment, incision and the bare and exposed banks and extremely tall bar formations. They will remain susceptible to lateral adjustments at flood stages until the river carves a wider corridor through the avulsion site.

The erosion threshold calculated for the Old Primary Channel resulted in a higher critical discharge than for the Confluence Area. The Old Primary Channel contained much coarser material that was harder to move and resulted in a more stable channel overall. The New Channel cut by the avulsion consisted primarily of sand. This sand has been transported downstream and is what has resulted in the lower critical discharge and a less stable channel in the interim. As the channel continues to adjust to find a new dynamic equilibrium with this finer sediment, sediment transport will continue to be higher than pre-avulsion conditions.

It is also important to remember that the critical discharge analysis is based on average conditions within the reach, and may not represent shorter segments of the reach. The New Channel, for instance, is highly variable. While portions of the bed are expected to be stable, others have been observed to be highly mobile.[3]

1.6.4 Pre- and Post-Avulsion Grade Adjustment

An examination of pre and post-avulsion channel grades and elevation changes was completed and compared with observations from the field. Pre-avulsion

---

[3] Riffle sediments through this reach were observed to be experiencing high rates of transport during flow conditions at the time of the field surveys. While exact flow conditions at the time have not been determined, records indicate 2.6 inches of rain in the 4 days prior to our survey. Water depths varied, but wading was difficult at many locations. It is estimated that the flow conditions were below bankfull stage.

grades were determined from the FEMA Flood Insurance Study completed in 1978. Post-avulsion grades were calculated from the survey work completed for this project. The following observations are from locations where the location of FEMA cross-sections coincided with our cross-section locations. To assess relative elevation changes, we assumed that the invert of our riffle section (XS1 – Short Falls Area, **Appendix C**) located just upstream of the Short Falls Road bridge was relatively unchanged by the avulsion event. This location also coincided with a FEMA cross-section. The following are the more significant findings relating to grade:

- The headcut at the avulsion site extends upstream to beyond the confluence with Little Suncook. There is a sizable headcut at the mouth of the Little Suncook, and evidence of a bridge collapse on the trail.
- At the point of the avulsion, the channel bed in the Old Primary Channel is elevated 12 feet above the existing channel bed.
- Slope above the avulsion site is 0.95 percent. Slope below the avulsion site is 0.17 percent.
- Our first cross-section (XS1) is at the upper extent of the headcut below Little Suncook. Comparison with the FEMA model suggests that the channel bed elevation is 3 feet lower than pre-avulsion conditions, suggesting degradation consistent with field observations of a headcut.
- Our cross-sections in the Confluence Area adjacent to Round Pond (XS4) shows channel bed elevations elevated 3 feet. This is again consistent with our observations of aggradation in this area.

  When compared to the FEMA study, our most downstream cross-section (XS9) from the Confluence Area is elevated by 4 feet above pre-avulsion data. The channel bed in this reach was observed to be aggraded close to the topographic bankfull condition.

1.6.5 Channel Type and Channel Evolution Models

Each reach was classified using Rosgen Stream Channel Classification System. The Rosgen system provides a useful discussion tool for comparing channel characteristics within the project area and with regional data. The channel evolution model as outlined by Schumm was developed independently from the Rosgen classification system, however many river managers have revised Schumm's model to incorporate Rosgen's classification methods. The Vermont Agency of Natural Resources adaptation was used in this study (VTANR). This method divides the channel evolution models in two groups based on whether the channel is single or multi-thread and recovering from degradation or aggradation, respectively. The channel evolution model can be used to help qualify a river's departure from stable and/or reference conditions.

The Reference Reach was determined to be of channel type B3c. This was due primarily to the entrenchment ratio of the channel which was on average 1.49. The dominant grain size through the reach was cobbles with a low slope. A review of aerial photography indicates that this reach has been stable over the past 50 years. In addition, the typical signs of channel adjustment were not observed in the field. Given the long term stability of the channel it does not fit clearly in a channel evolution schematic, which, by definition characterizes unstable and adjusting channel conditions.

The Reference Reach has experienced some encroachment leading to entrenchment from anthropogenic controls. Based on the imposed entrenchment, this reach would best fit into Stage I or Stage II of the F-stage channel evolution model. The channel evolution of stage II does not necessarily imply instability in this setting, but implies that several more stages will be required before the channel attains better connection with its floodplain and a greater entrenchment ratio. Channel adjustment processes occur on different time scales for different rivers. The timescale at which rivers erode can be partially linked to geology where more resistant materials will erode on a much longer timescales than, for example, sand or fine gravel rivers, which is the case in the New Channel.

The Old Primary Channel was determined to be of type B3c. This was due largely to the entrenchment of the channel through this section. This channel is no longer actively eroding its banks but appears to have had lost some connectivity with its floodplain and was in stage II of the F-stage channel evolution model. The Old Primary Channel is a bedrock controlled channel, which has, by definition, a dominant process of incision. Incision in bedrock channels is often very slow and field indicators of instability may not be present. Further supporting the assertion of Stage II, is the fact that sediment capacity far outweighed the sediment source since the channel was downstream of the Huckins Dam.

The Old Secondary Channel was determined to be of type C4b. The channel was only slightly entrenched with a moderate to high width to depth ratio (18.24). This channel is also no longer actively eroding following the avulsion but the channel appeared to have been stable. As with the Reference Reach, stable reaches are often difficult to type in a channel evolution model that characterizes instability and adjustment. Given the bedrock control and the fact that all source sediment was captured in the upstream dam, the reach probably best fits into Stage I of the F-stage channel evolution model. This was further evidenced by the good accessibility to the floodplain through this reach and well maintained bedforms.

The New Channel appears to be of channel type F5. The channel has a low entrenchment ratio and has recently undergoing rapid adjustments to grade and planform. For typing the evolutionary stage, the reach needs to be divided in two sections, the first being upstream of the avulsion location and the second being the avulsion area and the remaining reach downstream of the avulsion location. The channel is in Stage II of the F-Stage channel evolution model upstream of the avulsion site. From and including the avulsion site and downstream the channel appears to be in Stage III of the F-stage channel evolution model. Stage III follows the degradation occurring in Stage II and is typified by the initiation of channel widening and planform or lateral adjustments. The avulsion site and downstream have undergone significant lateral and planform adjustments since the initial incision during the flood of 2006.

The New Channel is an entirely new watercourse, so represents an extreme departure from previous morphology at this location. It is also a significantly different channel with different slopes and geology than the Old Primary and Old Side Channels that previously conveyed water around this reach. The May 2006 and April 2007 floods have already significantly widened the corridor. Water surface profiles at the bankfull discharge through the reach are wider and shallower than either the Reference Reach or the Confluence Area (see **Table 1-4** and **Appendix C**). Entrenchment in the New Channel is also less than in stable sections of the Reference Reach and Old Primary and Secondary Channels. It can be expected that the planform of the New Channel will continue to adjust in response to the new grade and sediment regime as has been observed in the 2006 and 2007 aerial photographs. The lateral adjustments will likely create a wider gorge through this reach and continue to be a source of sediment for downstream reaches. The channel corridor will likely continue to widen until sufficient sediment conveyance is lost and erosive forces on the banks are decreased sufficiently so that floodplain terrace can develop in the new corridor. It is not likely that this will occur quickly, but will take many decades or longer to evolve.

The Confluence Reach was determined to be of channel type C4 based on field measurements and observations. As a result of the avulsion and the large input of sediment to this reach, the channel has aggraded such that the bed elevation is at or near the floodplain elevation. The channel would have to be classified in stage V of the channel evolution process; however this does not represent a return to stable conditions as stage V typically does. As we have seen in other reaches, the relatively simple assumptions of the Schumm model breakdown because of the complexity and scale of the channel adjustment at this site. A likely scenario is that, if left to recover on its own, the river would enter a D phase channel evolution adjustment by avulsing and creating multiple channels in this area. The river through this area is likely to continue to undergo significant and long term adjustments as it seeks to regain an equilibrium condition.

2

Alternatives Descriptions

One key element of this study is the identification of a range of alternatives. Based on our field work, as well as discussions with interested technical partners and members of the public, a number of preliminary alternatives were identified that could address the issues caused by the May 2006 avulsion. Each of these preliminary alternatives is discussed in this chapter, and each is further evaluated in Chapter 3.

Note that the alternatives were developed only to a conceptual level. That is, the engineering was advanced only as far as needed to allow a basic understanding of the feasibility of each of the alternatives and to allow comparison among the various alternatives. Once a preferred alternative is identified, additional work would be needed to develop the full design plans needed for permitting and construction (except for Alternative 1, of course).

2.1 Alternative 1 - No Action

This alternative involves allowing the Suncook River and its tributaries achieve equilibrium through natural adjustment of their boundaries over time without any substantial intervention. (See **Figure 2-1**.) While this alternative requires no direct investment of public funds, there are substantial risks that need to be considered. The potential consequences of Alternative 1 are discussed in Chapter 3.

2.2 Alternative 2 - Strategic Treatments

Alternative 2 involves leaving the newly avulsed river channel in its current position but addresses channel degradation and aggradation at strategic locations along the system. (See **Figure 2-2**.) For example, control of headcutting in the main channel between the US 4 bridge and the avulsion site could be attempted through installation of several rock cross-vane structures in conjunction with channel shaping and grading to create bankfull benches.

Likewise, headcutting in tributaries feeding the post-avulsed river channel might also be adequately treated through installation of appropriately placed boulder grade control structures in conjunction with minimal grading and shaping of existing channel. **Figure 2-3** shows a schematic of a rock cross-vane structure. Structures similar to these have been installed in numerous rivers and streams over the last decade and have generally been effective at limited the upstream propagation of headcutting.

Field work to date has suggested that there are no hard points (e.g., bedrock outcrops) in either the mainstem of the Suncook or its tributaries that might arrest upstream migration of headcutting without intervention.[4] However, additional field work and geotechnical investigations prior to construction are recommended to confirm the need for the grade control structures discussed below.

2.2.1 Rock Cross-Vanes

Water surface profile data obtained from 1-foot contour interval aerial topographic mapping was analyzed in order to estimate the number of structures needed to control future channel degradation in the Suncook River, Little Suncook River, and Leighton Brook. Approximate locations for structure installation were also determined based upon significant grade changes observed in the water surface profile data.

Even though the May 2006 avulsion caused channel degradation which lowered the base elevation of the Suncook River between the avulsion site and US 4 Bridge Crossing, the existing river gradient along this reach of river is still relatively flat at less than 1 percent. Indeed, if one ignores the steepest section of this reach (the lower 700 feet), the river gradient is less than 0.3 percent. This relatively flat gradient, coupled with the existing coarse substrate material present throughout the reach, indicates that grade control can be easily achieved as long as the river still has good access to the floodplain. Since the avulsion caused channel widening and downcutting in this reach, the bankfull channel is over widened and floodplain connectivity is not as direct as it was prior to the avulsion. Hence, grading will be required to create bankfull benches inside the over widened channel and improve floodplain connectivity. In addition, two rock/boulder grade control structures are likely to be required to achieve stability in this reach (**Figure 2-4**). The upper structure would be installed approximately 200 feet below the US 4 Bridge crossing to ensure that the channel

---

[4] There are no published data for depth to bedrock available for the study area. The NH Geological Survey does have mapped data for public and private wells which contains some data on depth to bedrock. Unfortunately, relatively few wells are located in the study area. The single well closest to the area of interest (Well 079.0471) is located on the west side of the river, approximately 200 ft south of the US 4 bridge. Depth to bedrock at this location is 22 feet.

grade through the bridge structure remains stable. The lower structure should be installed approximately 700 feet upstream from the avulsion site in order to ensure grade control in this relatively steep segment of the river.

As discussed earlier, the May 2006 avulsion initiated headcutting in the Little Suncook River as well as Leighton Brook. The major headcut on the Little Suncook has advanced upstream approximately 350 feet to a point just above the old railroad crossing, which has created a relatively steep drop in this area of about 4 percent. Two rock boulder grade control structures may be required to arrest the headcut and to allow for proper dissipation of energy through this segment (**Figure 2-5**). Minor shaping and grading of the channel in the vicinity of the grade control structures may also be required to ensure sound structure installation and appropriate transition between structures. Decisions will also need to be made regarding treatment of the old railroad crossing and foundation members.

Based upon an analysis of the 1-foot contour mapping, it appears that a major headcut on Leighton Brook has advanced upstream approximately 300 feet and created a rather steep gradient of approximately 7 percent in the stream's lower segment. As many as four rock/boulder structures are likely to be needed to ensure grade control and proper dissipation of energy through the lower channel segment (**Figure 2-6**). A steep drop in water surface profile in the vicinity of the railroad crossing indicates that an additional structure may be required to provide adequate protection for the foundation.

The complete details of the channel and floodplain grading as well as the rock cross-vanes will need to be rigorously addressed in final design documents if this alternative is selected. Procedural elements that will help to ensure successful performance over time include proper grading of channel and floodplain to achieve equilibrium form; the use of large, angular boulders placed in an interlocking fashion to form a solid unit capable of withstanding the full range of river design flows; placement of large footer rocks to prevent structure undermining; keying downstream ends of the cross-vane arms sufficiently deep at "bankfull stage"; and establishment of dense native vegetation to form a minimum 50-foot wide buffer along left and right river banks.

As discussed in Chapter 1, bypassing of the Huckins Mill Dams has resulted in the loss of the impoundment upstream of the dams. Feedback provided during the March 2008 public informational meeting indicated that some Epsom citizens are concerned about the loss of the upstream flatwater recreational environment which was favored for canoeing and swimming. Alternative 4 (see below), combined with the maintenance of the Huckins Mill Dams, is the only alternative which has the potential to fully restore the impoundment. However, one objective for the design of the upper-most cross-vane on the mainstem of the Suncook (i.e., about 200 ft downstream of the US 4 bridge) could be to raise the existing grade, which reflects the lower, post-avulsion headcut elevation.[5] This would not restore the impoundment, but might bring water surface elevations closer to their pre-avulsion condition. We caution that several significant design issues are associated with this option, and it will not be clear as to whether this option is feasible or cost-effective until more work is completed during a final design effort.

2.2.2 Restoration of Bankfull Cross-Section in Aggraded Reaches

Additionally, channel reaches downstream of the new channel which exhibit severe aggradation would be excavated to restore bankfull cross-sectional area and appropriate sediment transport capacity. This measure is recommended to prevent further avulsions downstream of the main avulsion site.

It is critical to note that dredging of rivers can have significant adverse effects. Dredging is sometimes used inappropriately to remove deposited river sediments, or even native streambed material, in situations that do not call for it. Such dredging is usually unsuccessful, requires frequent maintenance, and can even cause unintended further damage to infrastructure, property, and ecological resources. Thus, dredging is a tool that must be employed in carefully considered and limited circumstances. However, we believe that this measure is required in at least a portion of the Suncook River within the study area as depicted in **Figure 2-2**.

In order to estimate the volume of material that would need to be removed, we compared two FEMA cross-sections from the original HEC-2 data with two new sections that were surveyed by VHB and Parish after the avulsion event.[6] (See **Figure 2-7**.) From these sections, an average depth was computed and used for a length of approximately 5,000 linear feet of river. Based on this quick method, we estimate that up to 32,200 cubic feet of sediment will need to be dredged to restore hydraulic capacity of the channel. While this is only a portion of the 150,000 cubic yards estimated to have moved from the avulsion site, we note that field observations indicate that the majority of the material that washed out of the avulsion site ended up within the floodplain.

There would be two main methods to dredge this material: 1) excavation, presumably behind cofferdams to contain the worksite, and 2) hydro-dredging, whereby a suction dredge would be used to pump slurry of sediment/river water from the channel. Either method would be relatively time consuming and

---

[5] The design of an "above-grade" cross-vane would consider a maximum height above the existing bed of no more than12 to 18 inches, which may or may not be enough to provide benefits to upstream flatwater recreation. This would need to be examined more closely during final design,

[6] We used FEMA Cross-sections M and N which correspond with cross-sections surveyed in 2007 by our field crew.

expensive, and both would have environmental impacts. However, as further discussed in Chapter 3, the dredge appears to be required to prevent an avulsion in the vicinity of Round Pond. Depending upon the ratio of total quantity of excavated sediment to floodplain disposal area it may be feasible to spread excavated material across adjacent floodplain areas if landowner permission were granted.

The purpose of dredging or removing sediment from the channel reach designated as the "Confluence Area" is to provide water and sediment capacity for all flows up to and including "bankfull" discharge. Returning normal channel capacity to this area will reduce the frequency of flooding in adjacent fields and minimize the potential for future avulsions in the vicinity of Round Pond. Careful consideration must be given in determining the appropriate width/depth ratio and slope combination to achieve sediment transport competency. In other words, the dimensions and slope of the dredged channel must provide for the transport of normal sediment loads delivered from upstream areas.[7]

2.2.3 Create Railroad Grade Permeability

Throughout much of its length, the historic railroad grade on the east side of the valley is elevated above the surrounding topography on fill. This means that the grade functions as a dike, preventing the river from accessing its entire floodplain, at least for certain flood flows. The restriction of flood flows to the western side of the grade can be expected to unnecessarily increase flood elevations and velocities for certain discharge events, thereby contributing to the potential for instability in the river. Confirmation of this would require a complete inspection of the railroad grade, which has not yet been completed. Hydrologic/Hydraulic modeling would also be useful, since the floodplain of the mainstem of the Suncook interacts with the floodplain of the Little Suncook in much of the area.

If the inspection and modeling indicate that the dike has a significant negative impact on the stability and/or natural function of the river, it may be prudent to consider ways of making the railroad grade "permeable" to floods. This could be accomplished by placing one or more new culverts across the grade, or by excavating portions of the grade down to original elevations. The purpose of this would be to allow flood waters to disperse to portions of the floodplain east of the railroad grade. Careful planning would need to be part of this component so

▼

---

[7] The effectiveness of the dredging in the Confluence Reach would be directly related to the delivery of sediment from upstream reaches. If excessive erosion in the New Channel persists, as we predict it will during events that exceed "bankfull discharge," the channel may simply re-fill, resulting in inefficiency. Thus, some measure to stabilize the material in the New Channel should be incorporated into the project. Chapter 3 provides further discussion and evaluation.

that existing recreational uses are not directly impacted (the corridor is currently used as a snowmobile and walking trail).

2.3 Alternative 3 - Alternative 2 plus Restoration of New Channel

Alternative 3 would implement Alternative 2 as defined above and restore the remainder of the New Channel to its equilibrium endpoint through the application of Natural Channel Design principles. (See **Figure 2-8**.) This would involve determining and implementing the river's most probable stable form (dimension, pattern and profile), given existing hydrologic and sediment regimes as well as site geology. In other words, the New Channel would be configured with appropriate dimension, pattern and profile to convey all flows up to and including bankfull, and be thoroughly integrated with an adequate floodplain such that all flows exceeding "bankfull" would dissipate across the floodplain. This application would provide self-maintaining channel stability and minimize the production of excess sediment through the New Channel.

As discussed in Chapter 1, application of Rosgen's Stream Classification System indicates that the New Channel is an F5 stream type (Entrenchment Ratio ~ 1.36; Width/depth ratio > 40; Sinuosity ~ 1.2; and Slope ~ 0.17 percent). While F5 stream types are inherently unstable, they also typically evolve toward a more stable C5 configuration by increasing entrenchment ratio values greater than 2.2, while decreasing width/depth ratio to values between 16 and 25. (See **Figure 2-9.**)

The current high width/depth ratio in the New Channel presents favorable conditions for the river to create an appropriate form (pattern, dimension and profile) inside the eroded oversized channel corresponding to bankfull discharge. Appropriate human intervention could be extremely beneficial and serve to accelerate the natural evolutionary process. Specifically, grading the existing valley materials to create an adequate floodplain would set the stage for relatively rapid development of appropriate "bankfull" channel characteristics and provide direct connection to a floodplain capable of adequately dissipating energy contained in flood flows including the 100-year frequency event. In addition, the grading operation could also be extended into the main channel to decrease the width/depth ratio and accelerate the development of bankfull hydraulic geometry. Flows occurring in the newly created wide and undulating floodplain would tend to pond in low areas and move slowly down valley so as to minimize flow concentration and the formation of new channels.

The required grading would be relatively easy and inexpensive since most of the work could be performed in the dry and the valley materials should be easy to manipulate to achieve the intended results. Natural boulder structures or rock cross-vanes similar to those described for Alternative 2 may also be strategically placed to provide for grade control, bank protection, and enhanced aquatic habitat. Total average floodplain width including left and right overbank areas needs to be on the order of 400 to 500 feet.

All graded and disturbed areas would be planted with appropriate native vegetation to establish a healthy riparian corridor capable of maintaining streambank stability and providing floodplain roughness to dissipate flood flow energy. Large woody debris could also be added to floodplain areas to further retard flood flows and enhance terrestrial habitat. A native forested buffer should also be established to ultimately provide for floodplain protection and optimal function.

As already stated above, Alternative 3 would also involve the work defined under Alternative 2, which includes installation of rock cross vanes at strategic locations above the avulsion site and removal of approximately 32,000 cubic yards of sediment from the river using either traditional excavation methods or hydro-dredging.

2.4 Alternative 4 - Restore the Suncook to Pre-May 2006 Avulsion Position

This would involve returning the main Suncook flows to the Old Primary Channel and making any necessary repairs to restore the two dam structures to a pre-avulsion condition, or complete removal of the dam structures. This alternative would also involve constructing a diversion dam in order to redirect the river and maintain flow through the Old Primary Channel. The diversion dam could be placed in one of two locations; at the avulsion site itself, or upstream approximately 700 feet from the avulsion site.

An overview of Alternative 4 is provided in **Figure 2-10**. Restoring the Suncook to its pre-avulsion position returns the full range of river flows to two stable channels: the Old Primary Channel and Old Secondary Channel. Removal of excess sediment, however, would still be required in the channel segment that runs between the outfall of the Old Secondary Channel and confluence with the Old Primary Channel in order to restore pre-avulsion capacity through this reach. The number of rock cross-vanes on the Little Suncook and Leighton Brook would be the same as for other alternatives, but the number on the mainstem of the Suncook might be reduced from two to one, or perhaps even eliminated entirely.[8]

2.4.1 Diversion Dam

Restoring the Suncook River to its original channel would require a replacement for the river bank and glacial deltaic feature that failed during the May 2006 avulsion. Considering that an estimated 150,000 cubic yards of sediment washed out of the bank during the event, the construction of a new "bank" will require a massive and highly engineered structure to restore the channel. This could be accomplished by building a diversion dam across the Suncook River to direct the current flow back into the original channel. Since significant downcutting upstream of the avulsion site has also occurred—so that the current river bed is below the old channel—the structure would also be required to raise water levels from where they currently lie, not just redirect flow.

A diversion dam could be constructed in two possible locations:

Alternative 4A (Figure 2-11): The first location is upstream of the avulsion site, where a cutoff channel through the original meander would be excavated. The dam would have to span both channels. Although the high ground in the center of the meander may be able to serve as part of the dam, its geotechnical properties would have to be further investigated. Given the nature of the highly erodible soils in the area, it is likely that some of the high ground would have to be excavated and replaced by more competent materials.

Alternative 4B (Figure 2-12): A second location for a diversion dam is at the old avulsion site, where significant downcutting has occurred. The dam would span the new river channel and redirect the water into the abandoned channel, essentially restoring the sharp bend of the original meander.

2.4.2 Regulatory Classification of Diversion Dam

For regulatory purposes, any structure that replaces the function of the original river bank that failed is likely to be classified as a "dam". According to the New Hampshire Department of Environmental Services (NHDES), dam *"means any artificial barrier, including appurtenant works, which impounds or diverts water, and which has a height of 4 feet or more…"* (NHDES, 2006). This would subject the diversion structure to NHDES regulations governing permit applications, dam construction, dam inspection, emergency action plans, and maintenance.

---

[8] The actual number of cross-vanes would need to consider hydraulic modeling that is beyond the scope of this study but which would be included in a final design effort.

NHDES dam regulations vary by hazard classification. Hazard classifications for dams are related to the potential damage that could occur in the event of a failure of the dam. If the breach of a dam is likely to jeopardize the safety of people, damage infrastructure likes roads or bridges, or result in significant property damage or environmental degradation, then the dam is subjected to more rigorous standards for engineering design, construction, maintenance, inspection and reporting. According to the New Hampshire Code of Administrative Rules, dam classifications include AA ("a dam that is not a menace"), A ("low hazard potential"), B ("significant hazard potential") and C ("high hazard potential"). Based on the damages caused by the May 2006 avulsion, it is likely that the diversion dam would be classified as a "Class B structure" due to its potential for "[d]amage to a public water system" (i.e., Town of Epsom groundwater well), "[d]amage to an environmentally-sensitive site", and "[m]ajor economic loss to structures or property". Ultimately the NHDES's Dam Bureau would make a determination about the hazard classification of a diversion dam.

The diversion dam's probable classification as a significant hazard, or Class B, structure has several important implications, as follows.

- The structure will be required to meet minimum factors of safety for one-half of the Probable Maximum Flood (PMF), which may greatly exceed the 100-year flood.
- The height of the structure will have to be at the level of one-half the PMF plus "wave run-up," a freeboard that is likely to be at least one additional foot above the flood level and maybe more.
- The structure will need to be inspected at least once every four (4) years.[9]
- The diversion dam will need to be designed by a professional engineer with at least five years of experience in the design of dams, with the site investigations, calculations and design reviewed by the NHDES Dam Bureau.
- An emergency action plan (EAP) will have to be prepared for the structure including inundation maps, notification procedures and the "responsibilities of individuals and agencies." Every four years a "test of the emergency communication network" will have to be performed, with continuous updating of the EAP.
- The structure will be subject to annual registration with the NHDES, including an annual fee of $750 per year for a significant hazard dam.
- Any proposal to construct a dam would have to meet the legal standard contained in RSA 482:9, V that states that the NHDES *"shall not permit the*

▼

---

[9] The NH Department of Environmental Services is contemplating increasing the inspection frequency for dams to every two years (Grace Levergood, NHDES Dam Bureau, personal communication, January 22, 2007).

> *construction…of any significant hazard potential...dam unless…the dam provides a public benefit....”* It is unclear at this time whether a diversion dam at either the upstream or the avulsion site would meet this regulatory requirement.

A Class B diversion dam—even if replacing a natural river bank—is not a simple proposition. Construction of a diversion structure will require that an owner (say, the Town of Epsom) commit to long term monitoring, inspection, maintenance, repair, registration and emergency action plan updates. Given the high profile avulsion that occurred at the site, any proposed structure would likely receive public and agency scrutiny. It is even conceivable that the NHDES would be reluctant to permit a new, significant hazard structure in such a dynamic environment, especially in an area where a major breach (avulsion) recently occurred.

2.4.3 Construction of Diversion Dam

The diversion structure would likely have similar construction to an earthfill dam. For purposes of the feasibility study, the following assumptions were made in analyzing a structure.

- A diversion structure could possibly be built upstream of the avulsion site, at the meander cutoff. (See **Figure 2-11**.) According to the survey performed by Eastern Topographic, the bed elevation in this area is approximately el. 315 ft. This bed elevation is lower than previously published data, such as the Town of Epsom Flood Insurance Study (FEMA, 1978), and probably reflects the headcutting that has occurred.
- A diversion structure could also be built at the location of the avulsion, essentially replacing the bank that failed in May 2006 (**Figure 2-12**). According to the survey performed by Eastern Topographic, the bed elevation in this area is approximately el. 310 ft, and reflects headcutting that has occurred.
- It was assumed that flood levels portrayed in the Town of Epsom Flood Insurance Study (FEMA, 1978) would be maintained in the vicinity of the cutoff and diversion. Any construction that raises published base flood elevations would not be permitted. As approximated from the flood insurance study to the nearest 1 ft, the water levels shown in **Table 2-1** would apply.
- To the nearest foot, the water levels are similar for both possible locations for a diversion structure.
- For a Class B (significant hazard) structure, the diversion dam would have to meet stability criteria for one-half of the Probable Maximum Flood (PMF).

Since the PMF is unknown, the 500-year flood was used to approximate one-half the PMF.

Table 2-1
Diversion Dam Design Flows and Elevations[1]

Flood Event	Peak Flow (cfs)	WSE (feet NGVD)[2]
10-year	5,875	334
50-year	10,255	336
100-year	12,715	337
500-year	19,650	339

Notes:
1 Data are from US Dept. of Housing & Urban Development, Federal Insurance Administration, Flood Insurance Study for Epsom, NH, January 1978.
2 WSE = Water Surface Elevation

- Overtopping of the diversion dam was thought to be undesirable. Although a lower structure could be built to convey some flow into the new channel during floods, the construction of a stable spillway (say, out of concrete) to allow overtopping would greatly increase construction and maintenance costs. Therefore, it was assumed that the crest of a structure in either location would be at el. 340 ft, which is the 500-year flood level plus 1 ft of freeboard.[10] Given that the bed elevation in the vicinity of the proposed upstream structure is el. 315 ft, the maximum height of this diversion structure would be 25 ft high. At the avulsion site, the maximum height of a diversion structure would be 30 ft. Conceptual cross-sections for both Alternative 4A and 4B are shown in **Figure 2-13**.
- As approximated from topographic mapping and flood study data, it was assumed that the diversion structures would vary in height. For conceptual planning, the following dimensions were assumed:

Upstream Diversion Structure (~1,300 linear feet)
500 linear feet at 25 feet high
200 linear feet at 20 feet high
600 linear feet at 6 feet high
Avulsion Site Structure (~800 linear feet)
140 linear feet at 30 feet high
200 linear feet at 25 feet high
460 linear feet at 10 feet high

---

[10] Comments received from the NH Geological Survey (NHGS) caution that the Mother's Day flood likely reached approximately el. 337 ft. The NHGS has therefore suggested that it would be prudent to construct the diversion dam to el. 345 (David Wunsch, NH State Geologist, personal communication, March 26, 2008). While we believe that el. 340 is a reasonable design, the final elevation would be subject to confirmation during final design and could be set higher than the elevation we assume here. The cost implications of varying dam heights are addressed in Chapter 3.

Based on the geology in the area, which appears to be glacial till underlain by the fine-grained sediments of glacial Lake Hooksett, it is likely that a steel sheet pile cutoff would have to be constructed on the upstream side of the structure. This cutoff would be necessary to control leakage underneath the dam, since the leakage could cause materials to be piped out of the dam, which could lead to settlement, sinkholes or even dam failure. The sheet pile could be as deep as the depth of water plus freeboard, unless intercepted by an impervious barrier such as bedrock. It is likely that the sheetpile would be partially driven and used for water diversion during construction of the structure.

In order to minimize flow through the dam, an impervious clay core would be installed and compacted. It was assumed that the core would go at least 5 ft below the bed elevation of el. 315 ft. The core would be surrounded by compacted fill, such as clean gravel. The crest of the dam would be 10 ft wide, which is 4 ft wider than the 6 ft minimum width required by NHDES regulations but would allow for equipment access. The side slopes of the dam would be 1:3 (vertical:horizontal). Although these slopes are flatter than the maximum slope of 1:2.5 specified by the NHDES, they are more typical of earth embankment construction. The entire dam would be covered by heavy rip rap, with the heaviest rip rap on the upstream side of the structure, where there will be flow parallel to the dam. Although the dry, or downstream, side of the diversion dam could be vegetated (say, with grass), this would require a flatter slope and more fill material.

Overall, the analysis and conceptual design for the diversion structure is quite simplistic relative to the amount of data and analysis that would be required to make such a dam a reality. More detailed geotechnical investigation and design could necessitate a larger structure or expensive features such as drains, gates and emergency spillways.

3

Alternatives Evaluation

This chapter provides a draft evaluation of the four main alternatives for addressing river corridor conditions resulting from the avulsion of the Suncook River in Epsom. The evaluation consists primarily of a discussion of costs and benefits associated with each alternative, with natural and anthropogenic site constraints affecting each alternative identified and discussed as needed. These include regulated floodplains and wetlands and infrastructure such as buildings, utilities, and roads and bridges. The draft evaluation considers the following criteria:

- Severity of stability and flooding problems and the potential for recovery without intervention;
- Potential impact to landowners and infrastructure;
- Ecological consequences; and
- Relative costs, including future operations and maintenance costs.

The following narrative describes the rationale of judgments and evaluations.

3.1 Stability, Flooding, and the Potential for Recovery without Intervention

We included Alternative 1, the “No Action” alternative, in our range of alternatives to provide a baseline against which other alternatives can be assessed, and to allow for consideration of whether public funds should be expended on any remedy at all. If the geomorphic assessment concludes that the river is close to a stable condition, and if it can be determined that the new channel geometry does not create additional risk of flooding to upstream and downstream properties, then the wisest course of action may be to do nothing and allow the channel to continue to develop without intervention. Our assessment, however, leads us to conclude that the No Action Alternative would allow continued instability and flooding, which can reasonably be expected to create further damage. This possibility is further discussed in Section 3.1.1 below.

3.1.1 Headcutting in the Mainstem and Tributaries

A headcut was initiated by the avulsion and appears to be actively migrating upstream. Pre- and post-avulsion assessment of channel grade depicts a channel that is undergoing active grade adjustment, with degradation (erosion) being the dominant process at and above the avulsion site, and substantial migration of a new meander feature in the New Channel. Severe degradation has occurred at the avulsion site; the elevation of the new stream channel is up to 12 feet lower than the old channel bed. This channel degradation has moved upstream to a point north of the confluence with the Little Suncook (i.e., an active "headcut" is moving upstream). The bed in this reach appears to be as much as three feet lower than before the avulsion. This bed erosion has contributed to the collapse of an old stone bridge on the railroad grade crossing of the Little Suncook River and is cause for concern for the existing US 4 Bridge just to the north. Active headcutting is also evident at the confluence of the new channel and Leighton Brook.

Thus, potential consequences of the No Action Alternative include the continuation of headcutting in the main river channel between US 4 and the May 2006 Avulsion Site as well as in tributaries feeding the main channel from the east, such as Little Suncook River and Leighton Brook. Based on our field work and understanding of similar sites, it can be expected that headcutting will continue to migrate upstream until bedrock or other erosion resistant feature such as roadway fill or a bridge foundation is encountered. As portions of the river channel become more incised (cut downward, thereby deepening the river channel) and cutoff from the historic floodplain, streambank erosion/failure will increase as the river seeks a new dynamic equilibrium at a lower elevation in the valley floor.

Because the scope of this project does not include geotechnical explorations, it is impossible to say with any certainty whether the headcutting will continue, and if so, how much additional erosion would result. However, the material that is currently visible on the surface of the riverbed above the avulsion site appears to be inadequate to completely arrest the headcut. For this reason, we have recommended the installation of grade control structures (rock vanes or similar) in certain locations in the mainstem and tributaries as a minimum measure.

3.1.2 Downstream Aggradation and the Potential for Additional Avulsions

Downstream of the avulsion, aggradation of fine material has raised the river bed such that the river bed is at the same elevation as the surrounding floodplain. Aggradation north of Round Pond has forced flood flows to spread out to the east into areas that were once considered outside of the 500 year floodplain, as was observed to occur in April 2007. Flows were running in newly formed flood chutes adjacent to the municipal well at this time.

The current volume of sediment in the channel below the avulsion site raises the possibility that a secondary avulsion may occur. This possibility is perhaps greatest below the confluence of the old and new channels, and above the large meanders at Short Falls Road, where only a small, vegetated berm keeps the channel in its present location. There is a high risk of large scale changes at this channel location.

There is also a newly forming flood chute on the west side of the channel which would bypass the first of the large meander bends if the channel does avulse here (Whittkop 2007, 2008 – see **Figure 4** of **Appendix D**). If left to evolve naturally and over time, there is a great risk of large scale changes to channel form and location below Round Pond and above the large meanders. The changes could come in the way of complete avulsion into the bypass channel on the west side of the river, lateral migration into the field on the east side of the river, and/or the formation of multiple channels. For this reason, dredging of this aggraded material is a component of all of the "Build Alternatives" - *i.e.*, Alternatives 2, 3, and 4.

3.1.3 New Channel Departure from Equilibrium

In addition to likely continued headcutting above the avulsion site, as well as the potential for further avulsion of the river downstream, the New Channel formed as a result of the avulsion will continue to adjust its highly erodible boundaries (sand/fine gravel) until a new self maintaining form (pattern, dimension and profile) is achieved.

In order to assess the viability of restoring a self-sustaining form in the New Channel, it is necessary to have a basic understanding of existing morphological conditions, degree of departure from equilibrium, and the level of effort required to achieve equilibrium or a balanced morphological state. Two geomorphic assessment tools, the Channel Evolution Model (CEM) as developed by Schumm, Harvey and Watson in 1984, and Dave Rosgen's Stream Classification System, can provide the user with an understanding of existing conditions as well as potential for natural recovery and/or restoration. For example, the CEM describes the equilibrium condition as well as the geomorphic processes (downcutting/headcutting, widening, aggradation, meander bend migration) or stages a river channel exhibits when it departs from equilibrium and evolves toward a new balanced state. Because no physical measurements are required, application of the model allows for a quick qualitative assessment of existing conditions, prediction of future channel adjustments, and estimate of the magnitude and scope of work required to restore equilibrium. Dave Rosgen's Stream Classification system can subsequently be used to validate and support CEM findings through quantification of existing, predicted and proposed conditions. Physical measurements of the stream reach such as width, depth, slope, sinuosity and streambed particle sizes are required in order to categorize or "type" the stream. Since the measurements, and hence, stream type imply hydraulic function, one can define existing conditions and predict future behavior. In addition, since many stream evolution scenarios have been observed and documented using Rosgen's Classification system, one can identify and quantify the most probable stable form.

Application of the CEM to field observations made by the VHB Assessment Team indicate that the New Channel is exhibiting late Stage III (Widening) and early Stage IV (Stabilizing) tendencies as defined by the CEM. In particular, during the avulsion and post-avulsion period, the river eroded and deposited valley materials, primarily fine gravel/sand, to develop a relatively sinuous plan form with distinct baseflow and bankfull channel characteristics present throughout much of the New Channel length. In addition, the upper 80% or so of the New Channel actually demonstrates predictable meander geometry as well as streambed morphological features. Floodplain features, however, are inconsistent and not well defined along the newly formed corridor, since the river has not had ample time to develop such features. In other words, the New Channel is somewhat incised and not well connected to a floodplain having the capacity to adequately dissipate energy contained in flood flows (i.e., flows exceeding bankfull). Consequently, the stable morphological trends currently exhibited in the New Channel are susceptible to erosion and sedimentation during events that exceed the bankfull discharge.

Application of Rosgen's Stream Classification System serves to advance our analysis and validate the findings of the CEM. Specifically, the average of morphological measurements taken in the New Channel, indicate that the New Channel is an F5 stream type. (Entrenchment Ratio ~ 1.36; Width/depth ratio > 40; Sinuosity ~ 1.2; and Slope ~ 0.17 percent. See **Appendix B** for data.) "F" streams are inherently unstable due primarily to low entrenchment ratios, i.e., less than 1.4 (disconnection from floodplain), and excessively high width/depth ratios indicating an over widened bankfull channel. While F5 stream types are inherently unstable, they also typically evolve toward a more stable C5 configuration by increasing entrenchment ratio to values exceeding 2.2, while decreasing width/depth ratio to values between 16 and 25. These adjustments in the morphological variables that define river form naturally occur over time as the river works and reworks available valley materials to conform to the range of discharges corresponding to bankfull as well as larger flows that ultimately determine the breadth of floodplain required for long-term channel stability.

The current high width/depth ratio New Channel presents favorable conditions for the river to create an appropriate form (pattern, dimension and profile) inside the eroded oversized channel corresponding to bankfull discharge. The over widened channel is the main reason we already observe impressive development of meander geometry as well as streambed morphological features. Lack of connection to a well developed floodplain, however, will significantly extend the time necessary for full development and long-term system wide stability to establish in the bankfull channel. This is because the larger flow events (5-year frequency and above) will tend to unravel the newly formed bankfull channel features until connectivity with an adequate floodplain for energy dissipation is achieved. It is impossible to predict the length of time that would elapse before with certainty because that is determined largely by the frequency and type of flow events. However, we suggest that the time would be on the order of decades.

Appropriate human intervention, however, could be extremely beneficial and serve to accelerate the natural evolutionary process. Specifically, under Alternative 3, the existing valley materials would be graded to provide connectivity with an adequate floodplain and to set the stage for relatively rapid development of appropriate bankfull channel characteristics. In addition, the grading operation could also be extended into the main channel to decrease the width/depth ratio and accelerate the development of bankfull hydraulic geometry. The required grading would be relatively easy and inexpensive since most of the work could be performed in the dry and the valley materials should be easy to manipulate to achieve the intended results

It is interesting to note that the sediment transport analysis appears to support the findings derived from application of the CEM and Rosgen’s Stream Classification System to the New Channel. Hydraulic results validate the notion that the New Channel is beginning to develop a form indicative of dynamic morphological equilibrium. Specifically, the Critical Discharge to Bankfull Discharge ratio (CD/BFD) as revealed in **Table 1-10** is 91 percent. Recalling that critical discharge is defined as the discharge that mobilizes the D50 particle size over a surface area greater than 50 percent of the bed surface, a CD/BFD ratio of 91 percent suggests that the bed sediments and existing channel geometry will remain relatively stable during flows up to and including bankfull discharge.
As discussed in Chapter 1, the existing low flow channel geometry in the New Channel may be sized appropriately for long term bed stability. The primary destabilizing factors in the reach are entrenchment, incision and the bare exposed banks and extremely tall bar formations. They will remain susceptible to lateral adjustment until the river carves a wider corridor through the avulsion site. The wider corridor could be created, as suggested in the preceding paragraph, through a relatively simple and inexpensive grading operation rather than letting the river carve and shape the corridor through erosion and deposition over a long period of time. Since the New Channel already exhibits significant

indications of morphological stability, most of the required grading would be performed to create an adequate floodplain with direct connectivity to the bankfull channel.

3.2 Potential Impact to Landowners and Infrastructure

The avulsion itself obviously created damage to private and public property in the form of flooding and increased erosion of property. Rather than focus this discussion on damage that has already occurred, which we believe has been adequately described elsewhere, this analysis is intended to address the likelihood of potential future impacts. As discussed above, there are four main areas where instability may cause further impacts to property owners:

- The headcutting on the mainstem above the avulsion site, as well as on the Little Suncook and Leighton Brook tributaries;
- The loss of the pre-avulsion upstream impoundment has impacted recreational use of the river above US 4:
- Continued channel adjustments in the New Channel reach, which could lead to the migration of additional sediment downstream; and
- Aggradation above and to the west of Round Pond.

Each of these areas raises the chance of additional damage.

3.2.1 Headcutting Upstream of Avulsion and on Tributaries

Headcutting has already led to the collapse of a historic cut-granite culvert structure on the Little Suncook River due to the lowering of the stream bed in this area. Thus, additional headcutting could lead to further damage to the railroad grade in this area. The grade, which is evidently used as a recreational path, is already impassible by the current damage. However, further damage would exacerbate the problem and make it more difficult to repair. While there has apparently not yet been similar damage to the railroad culvert on Leighton Brook, it seems likely that continued headcutting on that tributary could have a similar effect.

While the potential upstream limits of the headcut on the mainstem cannot be clearly determined without further information, we note that the headcut has progressed to a point approximately 300 feet downstream of the NHDOT-owned bridge that carries US 4/NH 9/US 202 over the Suncook River (i.e., more than 3,000 feet upstream of the avulsion). This raises a serious concern about the long term stability of the bridge crossing. NHDOT has been made aware of the issue and is monitoring the upstream limit of the headcut so that appropriate action could be taken to prevent damage to the bridge.

It is also important to note that headcutting is accompanied by the lateral adjustment of the river banks. Our assessment did not discover infrastructure which would likely be impacted by lateral adjustment, but bank erosion can be expected to continue to damage the agricultural property to the east of the river and the residential property to the west.

3.2.2 Loss of Upstream Impoundment

Prior to the avulsion, the Huckins Mill Dams created a long, narrow impoundment with the Suncook River which extended upstream at least two miles. Property owners along this reach of the river, especially the recreational users of the Epsom Valley Campground, had become accustomed to this flatwater environment, where flow was barely perceptible and the water levels varied very little. This type of environment was favored for swimming and canoeing.

With the bypassing of the dams and the lowering of the streambed at the avulsion site, the character of the river upstream has changed substantially. The flatwater is gone, replaced by a relatively shallow, free-flowing stream. The actual impact of this effect is difficult to determine, since the river is still available for recreation. However, long-time users of this reach can be expected to perceive a reduced recreational value. There is also some evidence that the drawdown of the impoundment has affected the availability of surface and groundwater near the river.

The loss of the impoundment can only be fully remedied through the implementation of Alternative 4, which would return flow to the Old Channel, including the Huckins Mill Dams. As discussed in Chapter 2, it may be possible to mitigate this effect under Alternative 3, but the effectiveness and feasibility of this measure can only be determined with further work during a final design phase.

3.2.3 Adjustment in the New Channel

Perhaps the most obvious example of property damage resulting from the avulsion is the loss of Cutter's Gravel Pit. Our assessment indicates that the New Channel is likely to continue adjusting horizontally to attain equilibrium, which would continue to impact this property. Alternatives 1 and 2 do not propose measures that would have a direct effect on limiting potential future property damage in this reach. However, Alternative 3 would minimize the likelihood of further uncontrolled damage by creating a channel form that is close to the predicted equilibrium point for a river of this type. It must be noted that, even if Alternative 3 were to be implemented, additional flooding would continue on the Cutter Pit and adjacent properties in areas which did not previously experience these conditions due to the river's new position in the valley. In addition, further lateral adjustment of the New Channel would be possible but minimized through the restoration effort.

It might be assumed that Alternative 4 would allow for the reclamation of Cutter's Pit. However, given the extent of the downcutting in the gravel pit that followed the avulsion, it seems likely that the bottom of the New Channel is low enough to have intercepted the water table. This means that, even if the river were put back to its former channel, the New Channel would likely be classified as a jurisdictional wetland, which would limit the potential for this area to continue to be a source of gravel. Thus, it is unclear whether there is any advantage to this landowner in restoring the river to its former channel.

3.2.4 Downstream Aggradation and Potential Future Avulsion

As discussed in the geomorphic assessment, a large amount of sediment has deposited in the channel downstream of the avulsion – particularly above the meanders north of Short Falls Road. In much of this area, the channel has aggraded with sand such that the river bed is at the same elevation as the floodplain topography. This is forcing flood flows to spread out onto the floodplain into areas that were once considered outside of the 500 year floodplain. If left to evolve naturally and over time, there is a great risk of large scale changes to channel form and location below Round Pond and above the large meanders. The changes could come in the way of complete avulsion into the bypass channel on the west side of the river, lateral migration into the field on the east side of the river, and/or the formation of multiple channels. Such an avulsion would have additional impacts to landowners who have already been impacted as a result of the 2006 and 2007 floods. Additionally, there is a substantial risk to the municipal well.

The risk of further avulsions downstream of the New Channel has motivated the recommended dredging of the Confluence Reach. The restoration of a bankfull channel capacity should help to minimize this risk. However, the effectiveness of the dredging could be significantly compromised if it is not combined with measures that would substantially reduce the sediment load to the restored channel reach. For that reason, we believe the most appropriate strategy would be to combine the downstream dredging operation with restoration/stabilization of the New Channel using Natural Channel Design principles (i.e., Alternative 3).

One suggested alternative to the dredging is the construction of a flood dike to contain the river within its current corridor and prevent an avulsion. Indeed, the USDA Natural Resources Conservation Service worked with the Town of Epsom in the 1980s and 1990s to design and construct such a dike in the vicinity of the town well to prevent flood damage in this location (Keith Cota, personal communication, February 26, 2008). However, we recommend against this approach for several reasons:

- Field inspection indicates that the dike failed at some point in the past, although it is not clear whether this failure is associated with either the May 2006 or the April 2007 floods. However, this failure suggests that construction of a dike is not a sustainable solution.
- Eliminating access of the river to its natural floodplain by constructing dikes along left and right river banks would artificially elevate the river above its natural floodplain, and hence, increase potential for future dike/channel failure and the need for increased maintenance. In addition, creating a dike along the right river bank would require significant disturbance of the riparian buffer area.
- The dike option also does not address width/depth ratio and slope parameters, which need to be adjusted in order to achieve balance through the Confluence Area.
- By replacing the dredge with a dike alternative, we predict that excess sediment loads would continue to be carried downstream, which would potentially cause further downstream ecological, infrastructure and property impacts.
- Although a conceptual design for such a flood dike has not been completed during this study, nor has any cost estimate been attempted, our experience suggests that the dike would be unlikely to have any clear cost advantage over the recommended dredging.

3.3 Ecological Consequences

The scale of the river avulsion makes clear that significant change in the habitat associated with the river has occurred. Approximately 150,000 cubic yards of sediment have been introduced into the river channel and associated floodplain, causing impairments of aquatic habitat and the communities that exist in that environment. The habitat and hydrologic modifications that occurred as a result of the May 2006 avulsion are extreme and include in-stream habitats, upland areas, wetlands, and adjacent surface waters. A full assessment of the habitat effects resulting from the avulsion is beyond the scope of this report. However, there are several ecological issues that are of obvious concern and which should be considered during the selection of a preferred alternative, discussed below.

3.3.1 Brook Floater Mussels

Approximately 1,200 brook floater mussels *(Alasmidonta varicosa)*, a state-listed endangered species, were rescued from the dewatered Old Primary Channel near Huckins Mill Dam after the avulsion. Rescued mussels were tagged, then relocated to two upstream sites on the Suncook in Chichester. These mussels are a strictly riverine species inhabiting small streams to large rivers with high to moderate flows. They are absent in scour-prone areas of high gradient streams and avoid high velocity flow channels. Although they show no consistent substrate preference (Strayer and Ralley 1993), brook floaters in New Hampshire are often found in gravel and in sand among larger cobble in riffles, along shaded banks, and, in higher gradient streams, in sandy flow refuges behind large boulders (S. von Oettingen, USFWS, and B. Wicklow, Saint Anselm College, cited in the NH Wildlife Action Plan, 2006). The Suncook River is one of only seven streams/rivers in NH that are known to have extant populations, and its populations appear to be more robust than most other locations (B. Wicklow, cited in the NH Wildlife Action Plan). Changes in the hydrologic regime of a river can seriously affect freshwater mussels.

As noted above, the brook floater appears to prefer sites with low to moderate embeddedness. Thus, the dominant sandy substrate in the existing New Channel appears to be poor quality for brook floaters, at least relative to the dominant substrate in the Old Primary and Old Secondary Channels, which is moderately embedded cobble/gravel/boulder material. Additionally, continued erosion upstream could prevent new colonization of freshwater mussels, including brook floaters, since unstable stream beds would be unlikely to provide optimal conditions for mussel habitat. And, downstream habitat could be affected as the sandy material is transported and is deposited downstream – perhaps in areas suitable for mussel colonization.

With regard to how brook floater habitat considerations might affect the selection of alternatives, it should be clear that the No Action Alternative would decrease the likelihood that brook floaters would re-colonize the river within the project study area. Similarly, Alternative 2 would be a poor choice for the future management of this species in the Suncook, since this alternative seeks only to arrest the on-going headcutting, would retain the sandy New Channel reach, and would allow continued downstream migration of sediment. Alternative 3 represents only a moderate improvement on the current situation, since it would seek to establish a stable reach in the New Channel which would limit the potential for downstream sediment impacts. (Alternative 3 could incorporate habitat features, including features such as course gravel-cobble riffles that would benefit the brook floater.)

It appears that only Alternative 4 presents a significant opportunity for the restoration of the brook floater to the impact reach. We conclude that the best chance for restoring the brook floater population at the Huckins Mill Dams would be to return the stream flow to the area that already contained a healthy population of the mussels. However, we caution against making an ecological decision based solely on this one species, albeit an important species, since it is not clearly understood what other species might benefit or be impacted.[11]

3.3.2 Relationship Between Bed Substrate and Habitat

Not only is bed substrate important for freshwater mussels, it is just as important for benthic invertebrates and fish species. The composition of the substrate determines the roughness of the stream channel and has a large influence on the channel hydraulics of stream habitat (Bain 1999). Stream segments with coarse substrate are important in providing attachment sites and microconditions favorable to supporting a diversity of aquatic macroinvertebrates (Allan 1995). Substrate dominated by fine sediment in flowing waters is unstable habitat and known to support a reduced density and diversity of macroinvertebrate taxa (Allan 1995). This is largely attributed to the lack of stability and tight packing of sand grains which reduce the trapping of detritus and can limit the availability of oxygen (Allan 1995). The rapid changes observed in the post-avulsion stream channel also suggest that the unstable reaches do not present optimal opportunities for epifaunal colonization, which would affect the entire invertebrate and vertebrate community in the river.

Fish are less constrained to life on the riverbed than macroinvertebrates; however the majority of freshwater fish, particularly the highly valued cold water species such as trout, select hard substrates (i.e., clean gravels) for reproduction. While the current project is focused on geomorphic data and does not seek to provide a habitat assessment, it is noted that relatively few fish species choose the sandy substrate that dominates the New Channel.
Also of ecological interest, anecdotal evidence strongly suggests that the current channel instability has resulted in episodic elevations of turbidity and suspended solids within the water column during storm events. It is well established that suspended sediment can have substantial adverse effects on the behavior, physiology and habitat of native fish species.

---

[11] Informal consultation with the NH Fish and Game Department and the US Fish and Wildlife Service has indicated that neither organization is likely to support Alternative 4.

3.3.3 Potential Avulsion into Round Pond

Round Pond is a kettle hole pond, which is a relatively rare geological formation. As a kettle hole pond, it has unusual bog vegetation surrounding it. Local naturalists report that the western side of the pond had a floating bog with pitcher plants and other bog-type plants including black spruce. Its protection is important, given the rarity of this type of habitat. The pond has provided recreation to the local community as an ice fishing location. It is reported to be only about 10 to 15 feet deep and had bass, pickerel, yellow perch and pumpkin seeds as well as bullheads, all typical warm-water fish species (Eric Orff, personal communication, March 4, 2008).

As discussed in the geomorphological assessment and in the sections above, a portion of the Suncook already flows directly into Round Pond as a result of post-avulsion deposition of sediment. There is a substantial risk that a secondary avulsion could occur which could change the course of the river into the pond.[12] This would not only have negative consequences for the future stability of this system, it would also have unpredictable ecological effects on the relatively unimpacted pond system. If this avulsion were to occur, the pond may act as a sediment sink which, ironically, might attenuate some of the downstream concerns. However, it would almost certainly lead to the eutrophication of the pond.

3.3.4 Impact to Forested Community Associated with Alternative 4A

Alternative 4A includes construction of a bypass channel through an area currently occupied by a mature white pine *(Pinus strobus)* forest. While this community type is one of the most common in New Hampshire, it would represent a potentially significant impact to upland wildlife resources. No other alternative currently under consideration would have similar impacts.

3.4 Relative Costs

This section provides order of magnitude conceptual cost estimates to allow for comparison among alternatives. Because these estimates are based on very preliminary concepts, there is a relatively high degree of uncertainty in their accuracy. However, the relative values among the alternatives should provide a reasonable basis for comparisons. All of the cost opinions should be considered

▼

---

[12] Apparently, the concern with flooding and potential avulsion is not new. It has been reported that the Natural Resource Conservation Service (a part of the US Department of Agriculture) conducted a project in the 1980s and 1990s to construct a levee in the vicinity of the town well (Keith Cota, personal communication, February 26, 2008).

approximate, since actual site conditions (such as ongoing erosion of the river bed) may drive up costs further. The geology at the avulsion site is considered to be especially challenging, with the glacial till and fine grained sediments meeting a deeply plunging bedrock outcrop.

Table 3-1 contains a summary of the data, and we provide a discussion of the various components of each estimate below.

Table 3-1
Preliminary Conceptual Opinions of Cost

Alternative	Estimated Cost
Alternative 1 – No Action	**$0**
Alternative 2 – Strategic Treatment	
Nine (9) cross-vanes	$350-450,000
Dredge 32,000 cu yds (5,000 lin ft)	$500,000
Remove and dispose of spoils (5 miles)	$325,000
Total	**$1,275,000**
Alternative 3 – Alternative 2 plus Restore New Channel	
Nine (9) cross-vanes	$350-450,000
Dredge 32,000 cu yds (5,000 lin ft)	$500,000
Remove and dispose of spoil (5 miles)	$325,000
New Channel Restoration	$500-750,000
Total	**$1.8- $2.1 million**
Alternative 4A – Bypass Channel	
Nine (9) cross-vanes	$350-450,000
Diversion Dam	$3.8 million
Dredge 32,000 cu yds (5,000 lin ft)	$0.5 million
Remove and dispose of spoil (5 miles)	$0.3 million
Dredge Bypass Channel	$0.4 million
Total	**$5.5 million**
Alternative 4B – Restore Avulsion Site	
Nine (9) cross-vanes	$350-450,000
Diversion Dam	$2.7 million
Dredge 32,000 cu yds (5,000 lin ft)	$0.5 million
Remove and dispose of spoil (5 miles)	$0.3 million
Total	**$4.0 million**

Notes: Diversion Dam cost estimates by Kleinschmidt Associates. Remaining items estimated by VHB. Costs do not include work needed to modify the railroad grade to the east of the river, which is included in Alts 2, 3 and 4, but which cannot be accurately defined at this time.

3.4.1 Alternative 1 Cost Estimate

There are no direct costs associated with this alternative since it proposes no new construction. However, it should be noted that there is a high probability of future costs in the form of property damage which is not accounted for in this analysis.

3.4.2 Alternative 2 Cost Estimate

There are several components to Alternative 2, each of which is discussed below.

3.4.2.1 Cross-Vanes

The estimate for the nine cross-vane grade control structures is based on the following:

- Two structures are recommended for the Suncook River, each requiring about 300 tons of rock boulder material.
- The two structures recommended for Little Suncook will require a total of about 300 tons of rock boulder material.
- The grades at Leighton Brook will require installation of four or five smaller cross-vanes, totaling about 400 tons of rock boulder material.
- Recent costs for rock/boulder material for similar projects have been about $50 per ton installed.
- Required shaping and grading along the corridor between the avulsion site and the US 4/NH 9/US 202 highway is estimated to be approximately $75 to $100 per linear foot.

3.4.2.2 Restoration of Downstream Bankfull Cross-sections in the Confluence Area

The cost of the dredging is based on a hydro-dredging method, with the following assumptions:

- Mobilization/demobilization of a hydro-dredge and crew is $ 50,000 (includes setting up pipe works).
- The total amount of sediment to be dredged is based on a comparison of two FEMA cross-sections from the original HEC-2 data with two new sections that were surveyed by the VHB team after the avulsion event. The average depth of new sediment in the channel was computed from these cross-

sections. Observations of the river suggest that about 5,000 linear feet would need to be dredged, equaling a total of about 32,000 cubic yards.

- Dredging would require keeping material moving at 14 feet per second which would equal 40 cubic yards per hour. This would equal 95 days at 8 hours per day to dredge the material.
- Dredging would cost about $15 per cubic yard for a total cost of $480,000, assuming about 32,000 cubic yards would be dredged.
- Other costs would be associated with constructing containment areas and dewatering areas on adjacent properties. Landowners may want compensation for temporary construction easements.
- Trucking and off-site disposal of the dredged sediment would add about $325,000 to the cost of the dredging. Depending upon the ratio of total quantity of excavated sediment to floodplain disposal area, it may be feasible to spread excavated material across adjacent floodplain areas if landowner permission were granted.

3.4.3 Alternative 3 Cost Estimate

Alternative 3 incorporates two components identical to Alternative 2:

- Installation of grade control structures in the mainstem of the Suncook, the Little Suncook and Leighton Brook; and
- Dredging of about 32,000 cubic yards of sediment from the channel downstream of the avulsion.

In addition, Alternative 3 includes reconfiguring the new channel to achieve a stable self maintaining pattern, dimension, and profile. The restorative design and grading plan would be based upon natural channel design principles, and as such, would serve to anticipate and accelerate the natural channel evolutionary process. Specifically, existing valley materials would be graded to provide connectivity with an adequate floodplain while the channel would be configured to achieve a width/depth ratio and sinuosity representative of a Rosgen "C5" stream type. It is anticipated that the proposed grading would not be difficult, since most of work could be performed under dry conditions using large track construction equipment such as dozers, loaders, and hydraulic excavators. In addition, construction activities would be staged and managed to minimize erosion and sedimentation, and any negative impacts to the aquatic environment. Following the grading operation all disturbed areas would be planted with appropriate native vegetation to provide for corridor stability and riparian diversity. Natural Boulder structures such as J-Hook Vanes, Cross-Vanes, and/or Log Vanes may also be incorporated in the newly configured river channel to provide for grade control, streambank protection, and enhanced aquatic habitat. Construction costs including riparian plantings associated with restoring the approximately 2500 linear feet of New Channel are expected to be on the order of $200 to $300 per linear foot for a total of $500,000 to $750,000.

3.4.4 Alternative 4 Cost Estimate

A conceptual design for the diversion dam was used to calculate a preliminary opinion of probable construction cost, largely based on the approximate quantities of materials required at each location. For the cost opinion, unit costs were derived from RS Means Heavy Construction Cost Data (2007), which uses synthesized costs from actual, built projects around the United States. RS Means cost data is widely used in the engineering industry.

3.4.4.1 Alternative 4A – Upstream Bypass Option

The preliminary opinion of construction cost for a diversion dam at the upstream location is approximately $2.55 million for construction, plus another $637,000 for geotechnical investigations, engineering and permitting, which were approximated as a typical percentage of the construction cost. A 20 percent contingency added to the construction and design costs would bring the total cost to approximately $3.82 million. This is neither the minimum nor maximum cost that it would take to construct the diversion dam, since changes in the assumptions for the dam’s height, length, and type of construction could influence the actual cost.

This option would require excavation of a bypass channel. Based on existing topography, this channel would be between 120 to 140 feet in width, with a depth of 10 to 15 feet. Its overall length would be about 480 linear feet. Therefore, the channel would require excavation of approximately 30,000 cubic yards of earth. This equates to about $75,000 for the excavation, plus about $325,000 for transportation and disposal of the excavated material off site for a total of approximately $400,000. Re-use of the material in the diversion dam could reduce this cost to about $185,000, or about $260,000 in total. This cost estimate does not take into account the cost of ledge removal (if encountered) or the construction of a haul road, which is assumed to be necessary.

3.4.4.2 Alternative 4B – Avulsion Site

The preliminary opinion of construction cost for a diversion dam at the avulsion site, which would require a shorter length than at the upstream location, is approximately $1.77 million for construction, plus another $442,000 for geotechnical investigations, engineering and permitting, estimated as a typical percentage of the construction cost. A 20 percent contingency added to the construction and design costs would bring the total cost to approximately $2.65 million.

3.4.4.3 Diversion Dam Height– Sensitivity Analysis

The conceptual design for Alternative 4 specifies that the crest of the diversion dam must be set at elevation 340. This is based on the current state rules determining the design of such a structure. However, there is some uncertainty associated with this assumption. For example, the height of the structure could be lowered if the Huckins Mill Dams were removed. Conversely, the NH Geological Survey has suggested that it may be more prudent to set the top of the lateral dam at elev. 345 since the Mother's Day Flood is estimated to have reached elev. 337 in this reach (David Wunsch, State Geologist, NHGS, personal communication, March 26, 2008).

Therefore, in order to test the sensitivity of the costs to structure height, a preliminary opinion of probable construction cost was also prepared for a shorter diversion structure at the avulsion site, with a maximum height of 27 ft rather than 30 ft. The construction cost could be lowered by approximately $349,000 with a shorter structure. The implication is that there would a tremendous incentive to lower flood elevations in the vicinity of the structure. Although detailed hydraulic modeling would have to be performed, flood profiles in the Town of Epsom Flood Insurance Study imply that removal of the Huckins Mill Dam could lower water levels in the vicinity of that dam by nearly 3 feet. Since the backwater influence of the Huckins Mill Dam extends upstream to the diversion site, there would likely be a lot of interest in removing the Huckins Mill Dam to minimize the cost and hazard potential of a new diversion dam upstream.

Conversely, if the Huckins Mill Dams were to remain, the cost of the dam could increase above the estimates provided here. If the dam crest were set at elev. 345 as suggested elsewhere, the cost of the dam can be expected to increase about $464,000 to a total of about $3.1 million.

Other factors, including rapidly escalating construction prices, could very well increase the cost of the lateral dam. Currently, construction costs in some segments have been rising at about 6 to 7 percent annually, far greater than general inflation. Costs for the diversion dam can therefore be expected by about $125,000 to $225,000 for each year that passes.

4

Summary & Findings

The Mother's Day Flood brought about significant changes for the Suncook River and significant impacts to many who live along the river. The April 2007 flood brought even more changes and more damage. The dramatic nature of these floods and their effects on the river and the communities through which it flows warrants a serious look at all of the possible alternatives. This study attempts to provide enough information to allow for an informed decision on how to move forward. Below, we summarize the key findings and recommendations that have developed over the course of the study.

Finding 1: The No-Action Alternative should be rejected. We draw this conclusion due to:

- The substantial risk of further property and ecological damage that would result from continued headcutting above the avulsion and in the Little Suncook River and in Leighton Brook. The risk includes potential damage to the US 4 bridge, which is just above an obvious nickpoint.
- The potential ecological and property damage that would result from a secondary avulsion near Round Pond, either into the pond to the east, or into an active agricultural field to the west.
- The continued mobilization of sediment from the New Channel reach that would have adverse effects on water quality, ecological resources, and potential downstream property impacts.

Finding 2: All of the measures contained in Alternative 2 are important to minimize the risk of further damage. Since there is substantial risk of further property and ecological damage, some specific actions should be taken as soon as possible to help manage this risk. This alternative includes the following components:

- Installation of two rock cross-vanes on the mainstem of the Suncook River;
- Installation of up to two rock cross-vanes on the Little Suncook River;
- Installation of up to four rock cross-vanes on Leighton Brook;
- Dredging of up to 5,000 linear feet of the New Channel to restore the bank full capacity of the river and help prevent a future avulsion; and
- Potentially creating openings in the railroad grade that parallels the river on its west side to allow the river to access its floodplain.

These measures will require further evaluation a design during a subsequent project development phase, but are thought to be relatively safe and cost effective ways to meet the project goal.

Finding 3: The most effective way to minimize the potential to future property impacts is to implement Alternative 3. Implementation of Restoration Alternative 3 would restore the "New Channel" corridor to an equilibrium form, and hence, minimize the production of sediment from about 2,500 linear feet of channel. This would be accomplished by creating a "C5" stream type with sufficient floodplain to move the river toward a stable equilibrium endpoint. Some key considerations are:

- One significant advantage of Alternative 3 is that it should stabilize the excessive production of sediment from the New Channel. This will benefit water quality as well as downstream property owners.
- Dredging the "Confluence Area" in the absence of restoring the "New Channel" as proposed in Restoration Alternative 2, may increase the need for future maintenance dredging since higher than normal sediment production could occur through the "New Channel" reach for decades to come.
- Implementation of Restoration Alternative 3, which also includes Alternative 2, provides the greatest potential for significantly reducing erosion through the project area, and hence, minimizing negative impacts to downstream areas.

Finding 4: Returning the river to its former channel through implementation of Alternative 4 is not the most cost effective way to minimize the chance of further property damage. Some in Epsom and in the downstream communities of Pembroke and Allenstown have called for action to return the river to its former course, with the concern that the avulsion is the cause of the recent extensive flood damage. However, the relationship between the flooding and the avulsion is probably not as strong as perceived. Our review of the river leads us to conclude that such an expensive and difficult course of action is probably not the most prudent action for the following reasons:

- The cost of Alternative 4 would likely be more than twice the cost of the next most expensive alternative.
- Anecdotal information indicates that it will be more difficult to obtain funding support from state and federal agencies for Alternative 4, since most funding programs would not support the construction of a new dam where practicable alternatives exist.
- Alternative 4 would be the most difficult to implement, with the design, permitting and construction of a lateral dam taking many years to complete.
- There is a substantial uncertainty associated with Alternative 4, since additional geotechnical work would need to be completed. Additionally, the construction of the structure at the location of the previous failure is

questionable, since the stability of this location has already been proven to be poor.

- The construction of a lateral dam would create a structure that would be regulated by the NHDES and would need to comply with all of the requirements for a dam. The operations and maintenance of such a dam would be a permanent cost on the entity that would own the structure, presumably the town.
- Other alternatives exist that would meet the primary project objective of preventing further damage to property and ecological resources.

Finding 5: Regardless of the specific alternative chosen, proper design and construction is necessary to ensure project success. Rivers are complicated, and the final design of the structures will take time. Proper installation of the grade stabilization/ habitat structures (e.g., cross-vanes) in accordance with final design and construction documents will minimize future maintenance needs and maximize potential for long-term stability.

Finding 6: Additional studies and engineering will be required to arrive at a plan that can be properly built. While a great deal of survey has been completed or is in progress, it should be noted that additional ground survey will be required to allow for final design. Additionally, geotechnical explorations and HEC-RAS modeling will need to be completed prior to or during final design. The design for any of the alternatives can be expected to take at least one year. Alternative 4 would likely take two to four years to design and permit.

Finding 7: The design for the selected alternative should be assessed based on the findings of two related studies that are currently in progress on the Suncook River. There are two on-going studies that have importance for the Suncook River. First, the USGS is re-mapping the floodplains along the river in light of the avulsion. Their study will also provide an understanding of sediment transport all the way to the Merrimack River – a much larger study area than this project reach. Second, FEMA has funded a study of how dams on the river might affect flooding. Since the findings and recommendations of these two related studies are not available at this time, we recommend that the design of the selected alternative be reviewed in light of these other study findings once available.

Finding 8: A post-construction monitoring and maintenance plan should be an integral part of the project. Proper design and installation will minimize the magnitude and frequency of any future maintenance requirements, but the first two to three years following construction are typically the most vulnerable years for channel and structure performance. Therefore, a short-term monitoring program, with provisions and funding for adaptive management if necessary should be included in the construction/implementation plan for the selected alternative.

5

Literature Cited

Allan, J. D. 1995. Stream Ecology: Structure and Function of Running Waters. London, England, Chapman & Hall.

Bain, M. B. 1999. Substrate. Pages 95-104 in M. B. Bain and N. J. Stevenson, editors. Aquatic Habitat Assessment: Common Methods. Bethesda, Maryland, American Fisheries Society.

FEMA, Town of Epsom, New Hampshire Flood Insurance Study. US Department of Housing & Urban Development, Federal Insurance Administration. January 1978.

Goldsmith, Richard, 1998, Surficial geologic map of the Gossville 7.5 minute quadrangle, Merrimack and Rockingham counties, New Hampshire: STATEMAP 1997, scale 1:24,000, Open File Map, Geo-169

Komar, P.D., 1987. Selective gravel entrainment and the empirical evaluation of flow competence. *Sedimentology*. 34:1165-1176.

Koteff, Carl, and Pike, Thomas J., 1998, Surficial geologic map of the Suncook 7.5-minute quadrangle, Merrimack County, New Hampshire: STATEMAP 1997, scale 1:24,000, Open File Map, GEO-120

Miller, J.P., McCave, I.N., and Komar, P.D., 1977. Threshold of sediment motion under unidirectional currents. *Sedimentology*, 24, 507-527.

Neill, C.R., 1967. Mean velocity criterion for scour of coarse uniform bed material. In: Chang, H.H. (1988) Fluvial Processes in River Engineering; page 90. Krieger Publishing, USA.

New Hampshire Department of Environmental Services, 2007. NH Code of Administrative Rules, Env-Wr 100-700, Dam Rules.

Olson, S.A., 2007. *Flood of May 2006 in New Hampshire*, U.S. Geological Survey Open-File Report 2007-1122.

Ontario Ministry of Natural Resources. 1997. Natural Hazards Training Manual. Provincial Policy Statement.

PARISH Geomorphic Ltd. 2001. *Geomorphological protocols for subwatershed studies*. Submitted to: Regional Municipality of Ottawa-Carleton.

Perignon, M.C. 2007. *Mechanisms governing avulsions in transient landscapes: Analysis of the May 2006 Suncook River Avulsion in Epsom, New Hampshire.* Pp 68.

Wittkop, C. and Bennett, D. 2006. *Geology of the May 2006 Suncook River Avulsion*.

Wittkop, C. 2006. *Suncook River Initial Assessment*. Inter-Department Communication – State of New Hampshire.

Wittkop, C. 2007. *Suncook River Long-term Observations.* Unpublished Memorandum.

Whittkop, C. 2008. *Suncook River Long-term Observations.* Unpublished Memorandum dated February 24, 2008.

Wolman, M.G., 1954. A method of sampling coarse river-bed material. *Transactions of American Geophysical Union.* 35: 951-956.

Glossary

Aggradation
The accumulation of sediment in rivers and nearby landforms. Aggradation occurs when sediment supply exceeds the ability of a river to transport the sediment.

Avulsion
A sudden and rapid change in the course and channel of a river.

Bankfull
The incipient elevation on a stream bank where flooding begins; associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain.

Bankfull Discharge
A flow condition in which streamflow completely fills the steam channel up to the top of the bank. In undisturbed watersheds, the discharge condition occurs on average every 1.5 to 2 years and controls the shape and form of natural channels.

Confluence
The place at which two streams flow together to form one larger stream.

Cross-vane
A constructed grade control structure that decreases near-bank shear stress, velocity and stream power. The structure will establish grade control, reduce bank erosion, create a stable width/depth ratio, maintain channel capacity, while maintaining sediment transport capacity, and sediment competence.

Floodplain
Land immediately adjoining a stream which is inundated when the discharge exceeds the conveyance of the normal channel. The “100-year Floodplain” is the portion of the floodplain which can be expected to flood once in every 100 years.

Fluvial Geomorphology
The study of rivers and streams and the processes that form them.

Freeboard
In dam design, a margin of safety added to account for waves, debris, miscalculations, or lack of data; the vertical distance between a stated water level and the top of a dam.

GIS (Geographic Information System)
A computer-based mapping and information management system tied to geographic data.

Headcut
A type of erosional feature seen in flowing waters where a deep incision of the streambed forms, lowering the streambed and usually causing the riverbanks to eroded and collapse. A headcut migrates upstream; its uppermost point is called a *nickpoint*.

HEC-RAS (Hydraulic Engineering Center – River Analysis System)
A computer program that models the hydraulics of water flow through natural rivers and other channels developed in 1995 by the US Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction.

Hydrology
The study of a watershed's behavior during and after a rainstorm. A hydrologic analysis determines the amount of rainfall that will stay within a watershed - absorbed by the soil, trapped in puddles, etc. - and the rate at which the remaining amount of rainfall will reach the stream.

Hydraulics
The study of floodwaters moving through the stream and the floodplain. A hydraulic study produces determinations of flood elevations, velocities and floodplain widths at each cross section for a range of flood flow frequencies. These elevations are the primary source of data used by engineers to map the floodplain.

Meander Belt
The zone along a valley floor that encloses a meandering river; the area between lines drawn tangential to the extreme limits of fully developed meanders.

Mainstem
The main channel of a river as opposed to the streams and smaller rivers (i.e., *tributaries*) that feed into it.

Nickpoint
The top of a *headcut*, usually characterized by an unnatural grade change which is the result of erosion.

Reference Reach

A river segment that represents a stable channel within a particular valley morphology. The reference reach is used to develop natural channel design criteria based upon measured morphological relations associated with the bankfull stage for a specific stable stream type.

Run of the River

Used to describe dams that allow all of the natural river flow to pass over the dam in a relatively a consistent and steady flow, vs. other dams which may divert, store, or release water flow for various reasons.

Tributary

A stream that flows into a larger stream or body of water at a *confluence*.

Watershed

A land area that drains into a lake, stream or river. Also called basin, watersheds vary in size. Larger ones can be divided into sub-watersheds.