Final Technical Report

Suncook River Avulsion, Geomorphology-based Alternatives Analysis

Epsom,
New Hampshire

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NH Department of Environmental Services

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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.