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Memorandum

To: Joni Kitson, Town of Epsom
Steve Couture, NHDES
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Date: February 20, 2008

Project No.: 51892.00

From: Peter J. Walker, VHB
Randy Sewell, VHB

Re: Suncook River Avulsion
Draft Alternatives Evaluation

I. BACKGROUND & OBJECTIVE

This memorandum provides a draft evaluation of the four main alternatives for addressing river corridor conditions resulting from the avulsion of the Suncook River in Epsom. This evaluation follows and incorporates the findings of two previous documents: 1) a geomorphic assessment of the river, as reported in the document *Geomorphology Based Evaluation of the Suncook River Avulsion, Epsom New Hampshire*, dated January 3, 2008; and 2) a technical memorandum dated January 7, 2008 entitled, *Alternatives for Addressing the May 2006 Suncook River Avulsion.* The information contained in this memo will be incorporated into a draft project report, along with the data contained in these two previous deliverables. Currently, we envision that a preliminary draft will be made available for public review prior to the March 26 public informational meeting.

The evaluation phase was envisioned to be primarily 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 evaluation considers the following criteria:

- Scope and severity of stability and flooding problems;
- Potential impact to landowners and infrastructure;
- Extent of ecological degradation;
- Potential for recovery without intervention;
- Potential to meet objectives with restoration measures;
- Project constraints and feasibility of installation;
- Uncertainty in assumptions;
- Ecological impacts of construction; and

- Relative costs, including future operations and maintenance costs.

Narratives describing the rationale of judgments and evaluations are included. Evaluations are summarized in both narrative and tabular formats.

II. SUMMARY OF THE ALTERNATIVES

Based on our field work, as well as discussions with interested technical partners and members of public, a range of four main alternatives were developed to address the issues associated with the Suncook River avulsion. Below, we provide a very brief description of each. Additional details are provided in our January 7, 2008 memorandum and will be included in the project report.

Alternative 1 - No Action

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

Alternative 2 - Strategic Treatment of Degrading and Aggrading Stream Reaches

Alternative 2 involves leaving the newly avulsed river channel in its current position but addressing channel degradation and channel aggradation at strategic locations along the system. Specifically, control of headcutting in the main channel between the NH 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. The upper structure would be installed approximately 200 feet below the NH 4 Bridge crossing to ensure that the channel 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. 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 exhibit severe aggradation would be excavated to restore bankfull cross-sectional area and appropriate sediment transport capacity. We estimate that approximately 32,000 cubic yards of unconsolidated material will need to be removed from about 5,000 linear feet of the existing channel (from reaches we have previously described as the “New Primary,” “Old Secondary” and “Old Primary” channels). 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 a slurry of sediment/river water from the channel.

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. 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. More specifically, the New Channel would be restored from an "F5" to a "C5" stream type (using the nomenclature of Rosgen's Stream Classification System), together with the creation of a floodplain with an average width, including left and right overbank areas, on the order of 400 to 500 feet.

The reconstructed New Channel would be able to convey all flows up to and including bankfull, and would be thoroughly integrated with an adequate floodplain such that all flows exceeding bankfull would dissipate across the floodplain. The intent of this alternative would be to provide self-maintaining channel stability and minimize the production of excess sediment through the New Channel. As indicated in the preceding paragraph, Alternative 3 would also require dredging of approximately 32,000 cubic yards of sediment from the river using either traditional excavation methods or hydro-dredging.

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

Restoring the Suncook River to its original channel would require a replacement for the river bank and esker 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. 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 would either be removed or repaired. 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.

This alternative includes two options that would achieve similar results:

Alternative 4A – A diversion structure could possibly be built upstream of the avulsion site, at a location that would cut off the meander in this reach. According to the survey performed by Eastern Topographic, the bed elevation in this area is approximately El. 315 ft.

Alternative 4B - A diversion structure could also be built at the location of the avulsion, essentially replacing the bank that failed in May 2006. 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.

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. 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. Such a dam would be classified as a "Class B – Significant Hazard" structure under state dam safety rules.

III. EVALUATION OF ALTERNATIVES

What follows is a discussion of the avulsion in general, with an evaluation of each of the Alternatives based on the evaluation criteria outlined in Section I.

Scope and Severity of Stability and Flooding Problems/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.

<u>Headcutting in the Mainstem and Tributaries</u>

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. 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, 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 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 NH 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 NH 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.

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 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 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). 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.

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 and documented in Parish's Geomorphic Evaluation Report, 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%). "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.

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. All graded and disturbed areas would be planted with appropriate native vegetation to establish a healthy riparian corridor capable of maintaining streambank stability. Natural Boulder structures similar to those described for Alternative No. 2 may also be strategically placed to provide for grade control, bank protection, and enhanced aquatic habitat.

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 10 is 91%. Recalling that critical discharge is defined as the discharge that mobilizes the D50 particle size over a surface area greater than 50% of the bed surface, a CD/BFD ratio of 91% suggests that the bed sediments and existing channel geometry will remain relatively stable during flows up to and including bankfull discharge. The Parish Report further states that "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 to which Parish refers 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. Total average floodplain width including left and right overbank areas needs to be on the order of 400 to 500 feet.

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 three main areas where instability could cause further damage:

- the headcutting on the mainstem above the avulsion site, as well as on the Little Suncook and Leighton Brook tributaries;
- 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 one of these areas raises the chance of additional damage.

<u>Headcutting Upstream of Avulsion and on Tributaries</u>

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 NH 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.

<u>Adjustment in the New Channel</u>

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, 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. 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 post-restoration 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.

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.

Extent of Ecological Degradation & Ecological Impacts of Construction

The scale of the river avulsion makes clear that significant change in the habitat associated with the river have occurred. Approximately 150,000 cubic yards of sediment have been introduced into the river channel 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.

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, 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 this reach of the river. 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. It appears that only Alternative 4 presents a significant opportunity for the restoration of the brook floater to the impact reach. Clearly, 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.

<u>Bed Substrate</u>

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.

Potential Avulsion into Round Pond

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. 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.

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.

Relative Costs, Including Operations and Maintenance

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

Table 1. Preliminary Conceptual Opinions of Cost

Alternative	Estimated Cost
Alt 1 – No Action	**$0**
Alt 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**
Alt 3 – Alt2 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**
Alt 4A – Bypass Channel	
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	**$5.0 million**
Alt 4B – Restore Avulsion Site	
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	**$3.5 million**

Alternative 1

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.

Alternative 2

<u>Cross-Vanes</u>

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 NH 4/NH 9/US 202 highway is estimated to be approximately $75 to $100 per linear foot.

Dredging of Downstream Sediment

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.

Alternative 3

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.

Alternative 4

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.

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% 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.

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% contingency added to the construction and design costs would bring the total cost to approximately $2.65 million.

Huckins Mill Dams – Sensitivity Analysis

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.

IV. LITERATURE CITED

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