IMPACT ASSESSMENT OF INSTREAM MANAGEMENT PRACTICES ON CHANNEL MORPHOLOGY

FINAL DRAFT REPORT

TO THE

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EXECUTIVE SUMMARY

Section 1: **Introduction**

This Section provides the rationale for the study and an outline of study objectives. In brief this study addresses the impact on channel form associated with gravel extraction practices and associated instream works for flood hazard management. This was done through a literature review of gravel extraction case studies, the development of a conceptual model for the explanation and prediction of channel response to gravel extraction, completion of a case study in a Vermont stream and validation of the model through application to the Vermont case study. Finally these findings were used to formulate recommendations for the management of Vermont streams as a basis for further discussion.

Section 2: **Literature Review**

In this Section a comprehensive review of case studies pertaining to the morphological impacts of gravel extraction from numerous States as well as Europe, Africa, New Zealand and Canada is described. In total observations from 70 different river systems in 11 countries were reviewed and summarized. Morphological impacts were found to be consistent for rivers of similar form and size regardless of geographical location, climate and topography. Consequently, generalities can be made from collective assessment of case studies. In general the morphological impacts varied depending upon the location of the reach relative to the mined reach, the size of the watershed, the amount of gravel extracted relative to the supply, stream type (braided, meandering, sinuous or straight) and whether extraction practices were active or inactive. In the majority of instances flood hazard benefits were short lived and the gravel mining resulted in the de-stabilization of the channel with a commensurate increase in property loss and aesthetic and habitat degradation in both the mined reach and reaches upstream and downstream of the zone of mining. The type of mining also had a bearing on the degree of morphological impact. The stripping of gravel bars had less impact then pit mining within the river. Pit mining within the floodplain was only an issue when lateral migration of the channel resulted in capture by the pit and avulsion of the channel system.

Section 3: **Conceptual Morphological Response Model**

The above studies were used to formulate a model for the prediction of morphological impacts using a decision tree approach. The model represents a comprehensive and unique approach to the prediction of the response of gravel bed rivers to a disturbance affiliated with gravel extraction and associated flood hazard reduction measures. The model provides a suitable format for the development of a smart systems computer model. Such a model would provide practioners and decision makers with a systematic methodology for the prediction of the morphological impacts associated with gravel extraction and associated instream works for the reduction of flood hazard.

Further, the model would be suitable for use in costing proposed mitigation works and therefore an instrumental step in the development of a prioritization algorithm for the allocation of limited resources.

Section 4: **Granville Case Study**

This Section deals with an analysis of historic aerial photographs for the White River through the Town of Granville (the "subject" channel). Photographs were available for the years of 1939, 1962, 1974 and 1995 for this region. The 1939 and 1974 photo series were subsequent to major flood flow and "maintenance" events (gravel mining and flood hazard mitigation works). The 1962 and 1995 photo series were taken 5 and 22 years after such events respectively.

The "subject" channel was subdivided into three distinct reaches: Reach 1 (upstream of the zone of mining); Reach 2 (the zone of mining from the Bowl Mill Bridge to a point downstream of the confluence of the White River and Alder Meadow Brook) and Reach 3 (downstream of the zone of mining to the first crossing of Route 100). The White River through the "subject" reach has experienced channel "maintenance" on four confirmed occasions since 1938 and possibly on a fifth occasion in the late 1920's.

The photographs were digitized and corrected for scale based on ground proofing. Morphometric parameters including the length of the thalweg, the width of the active channel, channel surface area, maximum and average normal shift were then determined for each photo year or Epoch. The same analysis was conducted for a "reference" channel. The West Branch of the Tweed River near Pittsfield was selected for this purpose because instream modifications were believed to be minimal and land use, topography, climate and watershed size were similar to that of the "subject" reach.

Pairwise comparison on the observations by Epoch indicates that the White River through the zone of mining has narrowed and straightened. Maximum and average normal shift were not determined for this reach because of the influence of maintenance activities. Downstream of the mined reach the channel has straightened and widened. Maximum normal shift has increased indicating increased lateral instability while average normal shift has declined. The later observation is consistent with channel straightening. The reach upstream of the zone of mining was not impacted because geologic controls prevent the headcutting of nickpoints and other grade discontinuities. In contrast, the Tweed River was found to relatively constant over the study period with a slight increase in width and normal shift. The morphological response of the White River is significant in comparison to the "reference" stream. The observed responses are also consistent with the observations reported from the literature review.

Section 5: **Validation of The Conceptual Morphological Response Model**

This Section describes the application of the conceptual model to the Granville case study. The model was applied to the three Reaches as defined in Section 4. Reach 1 showed no impact because of the step-pool form and bedrock control. Reach 2 has been subject to extensive gravel extraction and instream "maintenance" practices since the 1920's resulting in widening of the active channel and channel incisement. Large Woody Debris, large scale roughness elements (large boulders) and riparian vegetation have also been modified through the years. The model was also applied to the most downstream reach. Although some bank stabilization works are evident in this reach it is largely unmodified directly through gravel extraction practices.

Reach 2 is dominated by erosional forms resulting in Valley Formation. This process results in the formation of a new active-floodplain channel system inset within the existing system but at a lower elevation. This scenario was adequately predicted by the proposed model. The new channel has an increased flow conveyance capacity and consequently provides the intended flood hazard reduction but does so at the expense of considerable loss of property within the mined reach and the de-stabilization of the channel downstream of the zone of mining. The downstream reach is dominated by sedimentation forms leading to aggradation and the formation of chutes and cutoff channels. The formation of the bifurcation in 1998 was satisfactorily predicted by the model. Flood hazard in this lower reach initially increased as a consequence of the maintenance works. The development of the bifurcation resolved the imbalance between the elevated sediment load an the lack of stream competence by decreasing channel length and thereby increasing longitudinal slope and stream power. This interim quasi-stable form occurred with the loss of tillable farmland.

The proposed model indicates that eventual stabilization of Reach 2 and the commensurate decline in total sediment yield together with the fining of the sediment load may once again de-stabilize Reach 3. The lower reach will attempt to increase its flow length and thereby decrease its longitudinal slope to reduce its stream power to match its sediment load characteristics. It may accomplish this through increased meander development and propagation rates.

It was concluded that the proposed model provides a useful tool for the prediction of channel response to a disturbance for channel systems similar to the White River through the Granville reach. Further testing and development of the model is recommended for general application to Vermont streams.

Section 6: **Flood & Erosion Hazard Management**

The results of the literature review, Granville case study and the conceptual model were used to outline a general flood and erosion hazard management approach regarding instream works and gravel extraction practices in gravel bed streams in the State of Vermont. The recommendations are organized around watershed size and stream type (braided, meandering, straight) and they are intended for discussion purposes only.

In terms of watershed size channel systems of less than 38.6 mi^2 (100 km^2) were found to be very sensitive to instream works. In contrast channel systems in watersheds exceeding 386 mi^2 (1000 km^2) were found to be the least sensitive. Regarding stream type, braided channel systems were found to be the least sensitive while meander and straight channel systems were progressively more sensitive respectively. Consequently, gravel extraction in small channel systems is not recommended. Gravel extraction in moderately size watersheds may be permitted in braided systems and selected instances if a well defined management plan is followed. This may be defined using a sediment budget approach based on selected particle size fractions such that stream sediment load requirements downstream of the mined reach are satisfied. The instream programs must address issues of channel form and particle roughness, bed material gradation and structure, and the preservation of riparian vegetation and floodplain connectivity. Similarly, gravel extraction in large watersheds, particularly in braided channel systems, may be allowed in a controlled manor following completion of a well defined management plan.

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DEFINITION OF TERMS

The following terms are used in this text and their definition is provided here for the purpose of clarification.

Active Channel: the channel that conveys flow during dry weather periods and frequent flood flow events up to the flood flow rate having a recurring interval of one occurrence on average every one and one half to two years.

Aggrade: see Aggradation.

Aggradation: the deposition of sediment in the channel raises the base elevation of the channel.

Alluvial Channel: a channel formed in sediments reworked by the stream.

Avulsion: a rapid and catastrophic shift in channel form or position.

Bank Destabilization: refers to the transformation of a stable bank configuration to one that is unstable, leading to either massive failure of the bank or slow but progressive removal of bank material. This may occur by a number of processes. One common means of bank destabilization is bank oversteepening through erosion at the bank toe, also referred to as basal scour. In this instance bank material at the base of the bank is removed through erosion by stream flow. The result is often undercutting of the upper bank leaving an overhang (the upper portion of the bank is suspended above the channel bed) or oversteepening of the bank (the slope of the bank exceeds the angle of repose).

Bankfull stage (depth): that bank height within the active channel that corresponds to the bankfull flow.

Bankfull flow: the flow responsible for formation of the active channel that just fills the active channel. This flow rate has a recurrence interval of approximately one occurrence on every one and one half to two years.

Basal Unit: the bank stratigraphic unit overlying the channel bed at approximately one third bankfull stage.

Braided: to branch and rejoin producing a netlike pattern of channels.

Capacity (sediment): stream capacity is a measure of the total mass of sediment of any given particle size that the channel can move; **(hydraulic):** stream capacity is a measure of the maximum flow rate the channel can accommodate before spilling over the top-of-bank of the lowest bank.

Competence: refers to the largest particle diameter that the stream can move at a specified flow rate (normally computed at bankfull stage).

Degrade: to downcut of lower the elevation of the channel bed (see Degradation).

Degradation: a reduction in the elevation of the channel bed through the process of scour or nickpoint migration.

Downcutting: see Degradation.

Flood Plain Channel: that portion of the stream valley inundated by less frequent or rare flood flow events, e.g., those flows that exceed the conveyance capacity of the active channel (see Active Channel).

Geomorphic Activity Rate: The rate of change of a geomorphic parameter through time. For example, channel cross-section width changes by 10 feet over a period of 10 years. The geomorphic activity rate is 1 ft/yr. In the following 10 year period channel width increased by 2 ft/year. This represents a doubling of the geomorphic activity rate.

"Hungry" Water Syndrom: Clear water is capable of entraining larger particles and moving more sediment than sediment laden water. This condition may be related to the dampening effect sediment within the water column has on the vertical component of flow turbulence. The vertical component of flow turbulence is required to provide lift on a particle and to maintain it in suspension. "Hungry" water can be created by a reservoir or the armoring of a stream wherein the sediment load been carried by the stream is reduce relative to its capacity to carry sediment.

Incised: the channel becomes entrenched deeply into the surrounding terrain and functionally separated from its flood plain such that the capacity of the active channel exceeds bankfull flow.

Incision: the process of degradation resulting in entrenchment of the active channel (see Incised).

Morphological Impacts: This term refers to changes in the form of the river; these changes could be widening caused by bank erosion, deepening caused by degradation or changes in plan form shape (see Plan form).

Nickpoint: a nickpoint is a discontinuity in bed elevation encountered by the flow as it progresses downstream. The drop may be likened to the riser on the step of a staircase. As the water flows over the riser it accelerates. The acceleration increases erosion along the riser causing it to erode in the upstream direction. The whole step moves headward or upstream. As the step moves headward the riser may get progressively smaller. Eventually the riser becomes hydraulically insignificant relative to other stream roughness elements and it ceases to migrate upstream.

Plan Form: this term refers to channel forms when viewed from the air. For example, a meandering river has a sinuous form similar to a sine curve formed by a soundwave. The amplitude, wavelength and radius of curvature of the sine curve are examples of measures of channel plan form morphology.

Scour: the process of wearing away or eroding the channel bed or banks through the action (force and abrasion) of the sediment-water mixture being conveyed by the channel.

Sinuous: curving from side to side; winding like a sine wave.

Structural Failure: refers to damage or destruction of bridges, storm sewer outlets, pipelines, etc., that are located in or along the banks or bed of the channel. This may occur either by degradation of the channel bed which undermines footings and splash pads and exposes buried pipelines or through bank de-stabilization which outflanks and exposes the bank structures, or both.

Thalweg: the line joining the deepest points on successive channel cross-sections to form a longitudinal profile of the channel bed.

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SECTION 1.0
INTRODUCTION

1.1 Background

Gravel extraction and instream works for flood hazard abatement (maintenance) have been common practice in Vermont channels up until 1985. Channel instability resulting in property loss, as well as degradation of aesthetic and habitat value lead the State of Vermont, Department of Environmental Conservation to regulate these activities through a permitting program. The permitting process significantly reduced the amount of gravel extraction and flood hazard mitigation work undertaken in Vermont channels since its inception. Proponents of continued "maintenance" argue that the lack of such work has resulted in the development of massive gravel bars within many channels. These bars deflect the flow conveyed by the channel into the banks contributing to bank failure and property loss. The influx of bank sediment also contributes to the loss of flow conveyance capacity necessary for flood hazard abatement. Record floods on June 28, 1998 lead to a renewed interest in the "maintenance" approach to channel management for flood and erosion control based on this "common sense" approach. This approach, however, ignores natural stream processes. Other alternatives have been put forward that work with the morphological tendencies of the channel system and are, consequently, more sustainable and less maintenance intensive. Proponents of the "alternative" method of channel management argue that the massive bars are a consequence of the disruption to channel processes caused by the "maintenance" activities and that the use of the term "maintenance" is itself indicative of the conflict created between the imposed and natural tendencies of the channel system. The acceleration of property loss and structural damage to bridges, roads, culverts, storm sewers and pipelines associated with gravel extraction practices is well documented. As a result of studies on the impact of gravel mining on bridge structures the US Agency of Transportation (USAoT) and the Federal Highway Administration (FHWA) will not make federal funds available for bridges damaged by such practices. Further, there is considerable debate as to the flood hazard benefits actually attained through the "maintenance" approach.

1.2 Study Objectives and Approach

A river channel forms in response to both the water and sediments generated within a watershed. A stable channel form is one in which the forces acting on the boundary are balanced with the resisting forces such that the channel is just able to move it's sediment load. When the sediment load is altered through in-stream gravel extraction practices, this balance is upset and morphological impacts often occur. As noted above, gravel mining and associated instream works for flood and erosion hazard control have been common practice in Vermont streams up until 1985. These practices have come under question because of apparent morphological impacts. The purpose of this study was to:

i) determine if morphological impacts from gravel extraction and instream works experienced in other geographic locations can be applied to Vermont conditions;
ii) develop a conceptual model for the prediction of morphological response to instream disturbances based

on the findings from the literature review;
iii) examine the morphological response of a Vermont river to gravel extraction and instream maintenance practices;
iv) validate the conceptual model though application to the Vermont case study; and,
v) derive general guidelines pertinent to the management of Vermont streams based on the above findings.

1.3 River Form and Balance

A river's function is to transport water and sediment through the landscape. In all regions, humid, semi-arid, mountainous or flat, the river's function is the same. Luna Leopold wrote in "*A View of the River":*

> *"Mountains on the continental surfaces are gradually worn away by the ubiquitous weathering of their rocks, and the transport of weathered products downhill by the action of water, wind and gravity. The weathering processes that change hard rocks to erodible material incorporate water at every stage. Furthermore, water is the principal agent of movement of the weathered material that makes up the soil and supports vegetation, of the sedimentary rocks formed by the accumulation of the weathering products, and of the channels along which they are carried."*

Consequently, the primary geomorphic function of a channel is to convey sediment and water generated through weathering and hydrologic processes in the watershed within which the channel has formed. Since alluvial channels are able to adjust their boundaries the form of the channel is a product of the physical characteristics of the materials within which the channel is worn and the quantity and properties of the sediments and flows conveyed by the channel.

A stable channel form is one in which the forces tending to erode the channel boundary within which the channel is worn are just balanced by the resistance of the materials (1), such that the channel is just able to move its sediment load. Lane (1952)[1] (2) describes this balance as a proportionality between the physical characteristics and mass of sediment carried by the river and the ability of the river to perform work as measured by the product of slope and flow rate. This balance is dynamic in that vagaries in the flow and sediment inputs cause the channel to alter its morphology. The channel is considered 'stable', however, if these alterations do not represent a change in mean channel dimensions beyond a consensual range of variance over some predefined time period. A change in boundary material composition, the hydraulic characteristics of the channel or the magnitude and physical characteristics of the sediment supply to the channel represent potential disruptions to this balance. Depending upon the magnitude of these disturbances and the sensitivity of the channel system, morphological adjustment could occur. The extraction of gravel from the river bed constitutes such an impact by altering the sediment regime. Instream works such as channel armoring, enlargement and the removal of Large Woody debris and riparian vegetation alter channel hydraulic geometry, boundary material resistance to scour and the hydraulic characteristics of the channel. These modifications may also result in morphological adjustment to the channel.

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[1] Lane, E.W. (1955). "Design of Stable Channels", American Society of Civil Engineers, transactions, 120. Pp. 1234-1279

SECTION 2.0
LITERATURE REVIEW

2.1 Methodology

This study used a two track approach to acquire information on the impacts of gravel extraction from bar scalping (or skimming), instream pit mining (dredging) and flood plain mining. An Internet and database search was complemented with phone interviews and e-mail correspondence with professionals (Appendix A-Sec 2) on the impacts of gravel extraction. The literature review focused only on morphological and flood related impacts while comments from professionals in the field were more far ranging. Summaries of the correspondences and papers reviewed as well as a detailed discussion of the key findings from the literature search are presented in Appendix A Section 2 of this report.

A table format covering key physical attributes and impacts was used to standardize the review and reporting process. Some of the studies did not contain all of the information on the physical attributes and morphological impacts outlined in the table. Never-the-less, the majority of the studies contained sufficient information to be sufficient for comparison with other studies and subsequent interpretation of the reported findings. Tables A2 to A19 in Appendix A Section 1 document the main findings from each relevant study.

The studies were divided into two categories. Those that gave watershed specific information, and those that contained overall reviews or analysis of gravel mining impacts. Tables A2 to A18 contain watershed specific information (case studies). Studies that contained only review information are cited by river in Tables A19. This method was adopted to avoid duplication of information. For example, if Chache Creek was mentioned in more than one study, it only got one listing in Tables A2 to A19.

Only information written in the studies was included in the tables. For example, personal knowledge could inform one on the climate or hydrology of the Alps or Cascades, however, if that information was not provided in the study it was not catalogued in the tables. This was done to minimize interpretation of the paper. The information in Tables A17 and A18 was provided by Mr. Randy Klein, a consulting hydrologist, for three rivers with which he was personally familiar. This information came from published and unpublished studies prepared by a professional in the field.

The literature review included an Internet and database search using the key word combinations, some of which yielded no results, listed in Table 2.1. Notes and information from interviews with professionals in the field are found in Appendix A Section 2 The phone interviews lead to Aldaron Laird, Scott McBain and Bill Trush of California and Mike Roell of Missouri. These researchers are conducting literature searches on the impacts of in-stream gravel mining for the National Marine Fisheries Service (NMFS) and the Missouri Department of Conservation. Reference lists form Larid, McBain and Trush and draft copies of Mike Roell's work were used to find applicable studies. Reference lists from these studies were used to identify other pertinent publications. Following identification of relevant publications the Vermont Department of Libraries conducted the database search to locate the publications.

Table 2.1 Summary of Key Word Combinations Used in Internet Search

Key Word Combinations	**Some Yielded Results**	**Yielded Results**
river gravel extraction/river gravel mining/stream gravel mining/geomorphology in-stream management/flooding rechannelization geomorphology/channel alteration geomorphology/river gravel dredging/stream channel enlargement/stream Channel geometry alterations stream blockage removal/river debris removal	●	
gravel extraction/debris removal/gravel mining/river debris/stream blockage/blockage removal/stream channel geometry/stream channel enlargement/gravel dredging/geomorphology channel/rechannelization stream mining/gravel mining and streams/stream management		●

2.2 Summary of Case Studies and General Observations

Data from a review of case studies in the literature included observations from 70 rivers in 10 different States within the U.S.A. as well as observations in seven other countries around the world. The countries other than the United States include:

1) Austria
2) Canada
3) England
4) France
5) Japan
6) Kenya
7) New Zealand

The review papers included many of these case studies and other data including data collected in Taiwan. This assessment focuses on the case studies. Physical data describing the case study watersheds, their approximate size and location, are summarized in Table 2.2. The case studies represents a good cross-section of watershed sizes, geographical locations, stream types (braided, meandering, etc.) and climatic regimes.

In summarizing and interpreting the case studies some discrepancies may occur due to differences in the definition of terms used by the various researchers. Despite this potential problem the literature review demonstrates that rivers in Europe, Japan, Africa, New Zealand as well as Alaska and the continental United States (despite widely varying climate, topography, surficial geology and other basin characteristics), typically exhibit similar morphological responses to in-stream gravel mining. These impacts vary with:

a) the location of the subject channel segment relative to the mined reach, i.e. upstream of the mined reach; downstream of the mined reach; and, within the mined reach;
b) the magnitude of the disturbance making the impacts scale dependent;

c) the method and history of extraction, i.e. current (active) or historic (inactive); and,
d) other intervening factors such as geologic controls, changes in land use and flow control structures.

Table 2.2 Summary of Rivers Cited in the Literature as Case Studies on the Morphological Impacts of Gravel Extraction Practices

Ref.	River	Location	CDA (mi^2)	Ref.	River	Location	CDA (mi^2)
46, 14, 7	Skykomish	Washington	535	42	Naugatuck	Connecticut	307
74	Mad	Vermont	139	74	White	Vermont	18
74	Trout	Vermont		74	Browns	Vermont	92
70, 61	Puyallup, White & Carbon	Washington	1000	54	Clackamas	Vancouver	
59	Middle Arve	France	766	43	Crooked	Arkansas	462
39	Lower Mississippi			80	Lower Mackenzie, Stony Ck	Oregon, California	741
4	Illinois King & Crooked Ck	Arkansas	672, 530, 300	15(a)	Amite, Tanoa, Boque Chitto, Buttahatchee, Tombigbee	Mississippi, Lousianna	
17, 7	Dry Ck	California	217	79	Salzach	Austria	
58	Griffre	France	125	7	Lower Manawata	New Zealand	2300
19	7 Small Basins	Alaska	<39	65	Athi, Thwake, Keiti & Muooni	Kenya	
19	13 Medium Basins	Alaska	39 to 386	12, 12(a),7	Russian	California	1484
19	5 Large Basins	Alaska	>386	8	Redwood Ck	California	278
27	Amite	Louisiana	772	3	Little Bighorn	Oregon	239
7	Humptulips Wynoochee	Oregon			Lower Eel	California	3113
7	Cache	California	1150	68	Wooler	England	20.3
67, 80, 5	Tujunga Wash	California	115		Water		
	Mad	California	485		Lower Van Duzen	California	426

CDA is the Catchment Drainage Area,
Reference (Ref.) numbers refer to the citations provided in Reference section.

A summary of the main findings from the review of these case studies is provided in Table 2.3.

The above morphological impacts have been observed with all types of gravel mining including scraping, in-stream pits and flood plain pits. Although avulsion was more evident when instream pits were used or when a floodplain pits captured the channel flow, this specific form of adjustment was not commonly reported. On a more general note, gravel mining tends to:

i) cause the mined reach of the channel system to become incised; and,
ii) initially reduce the supply of coarse material to the downstream reach.

These initial impacts de-stabilize the channel system followed by a myriad of adjustments as the channel attempts to find a new balance between sediment load, boundary erodability and the forces exerted on the boundary. The adjustment process may either be discontinuous but generally progressive or catastrophic. Once a reach has become incised its flow conveyance capacity increases and it is more susceptible to bank erosion and property loss during high flow events and catastrophic failure during rare flood flow events. Flood damage and bank erosion also result in damage to or premature failure of riparian structures such as bridges, fords, storm-sewer outlets and pipelines. The US Agency of Transportation (USAoT) and the Federal Highway Administration (FHWA) have documented negative impacts to bridges caused by degradation associated with in-stream mining. As a result, federal funds are not available for bridges damaged by gravel mining.

The following sub-sections provides a general description of the impacts of gravel mining for the three relative segments as noted above.

2.2.1 Common Impacts Within The Mined Reach

Common initial impacts of in-stream gravel extraction within the zone of mining include:

A. incision (disconnection of the active channel and its floodplain);
B. bank collapse;
C. channel widening;
D. degradation (deepening of the bed);
E. channel straightening; and,
F. a decline in sinuosity.

The exceptions to these general findings appears to be related to the type of channel system and the magnitude of the extraction relative to the supply of material. Channel systems that were initially braided became narrower and single thread systems as incisement occurred if extraction exceeded supply. Another possible variant is related to whether gravel extraction is active or inactive and the degree of instability within the upstream channel segment. If gravel extraction is inactive and large quantities of sediment are entering the channel through adjustment processes in the upstream channel segment, then aggradation can occur within the mined reach. Where the longitudinal slope in the mined reach is sufficiently steep to pass the increased sediment load on to the downstream segment, downcutting may continue within the mined reach until other negative feedback mechanisms arrest this process.

Table 2.3. Summary of Impacts Of Gravel Mining From Literature Review of Case Studies

River (Ref.)	**Location & CDA (mi^2)**	**Impact u/s of Mined Reach**	**Impact d/s of Mined Reach**	**Impact Within Mined Reach**	**Extraction History**
Mad (74)	Vermont (139)			W8, Ins, Deg,	1986
White (74)	Vermont (. 18)	Geol	Agg, W8	W8, Ins, $Q_{CAP}>Q_{MF}$	1998
Trout (74)	Vermont			Ins, Deg, W8	1997
Browns (74)	Vermont (92)		Agg	W8, Deg	1980's
Skykomish (46,14,7)	Washington (535 & 1780)			W8, Agg, Bra, Shifting	Active since 1961
Naugatuck (42)	Connecticut (307 mi^2)	Bar9, Geol	W8, Bar9	Γ9, W8, Deg	1980
Puyallup, White & Carbon (61)	Washington (1,000)			Ins, Agg (limited reaches)	Active
Salmon Ck, Clackamas (54)	British Columbia, Oregon (n/a)	Hcut		Ins, Deg, S8, Γ9, Str, Avul	N/r
Middle Arve (59)	France (766)			initially W8,then Deg, Ins, Bra6Single Thread, W9	Active
Crooked (43)	Arkansas (462)	Hcut, W:d8	Agg, φ8, W:d8	Ins, W8, φ9, W:d8	1969
Lower Mississippi (39)	N/r (N/r)		Chutes, φ9, Multiple Channels	W8, φ9	Active
Amite, Taniphahoa, Boque Chitto, Buttahatchee, Tombigbee (15a)	Louisiana (N/r)	Hcut		Γ9, Ins, W8, S8, Mea6Str	Active
Illinois, King & Crooked (4)	Arkansas (300, 672 & 530)		W8	W8, Hom, PoolL9 (2 of 3), PoolL8 (1 of 3)	N/r
Salzach (79)	Austria			Ins, Deg, AL6RC, W9, Bra6Single Thread, φ8	Active

Table 2.3. Contd.

River (Ref.)	**Location & CDA (mi^2)**	**Impact u/s of Mined Reach**	**Impact d/s of Mined Reach**	**Impact Within Mined Reach**	**Years Since Extraction**

Dry Ck (17, 7)	California (217)	Hcut, AL6RB		W8, ΔS=0, Deg, Ins, W:d8, d8	N/r (dam u/s 1950)
Russian (12, 12a,, 7)	California (1483)		Deg, W8	Ins, W8, Deg, S8, d8, Bars8, Γ9, Win, $d_P:d_R$9, α9 $Q_{ACT}>Q_{BFL}$	Active
Stony Ck (25)	California (741)	Bra6Ins, ξ8, W8	φ9, W9, Ins, Deg, Γ8	Bra-Single Thread, Deg, initially W9 now W9, Ins,	Active
Wooler, Water (68)	England (20.3)	Hcut		Ins, Deg, Initially W8 Currently W9, ξ8,	1979
Little Bighorn (3)	Montana (239)		Agg, Γ9, W8	Deg, $Q_{CAP}>Q_{BFL}$, S8, Γ9, W8	1987 (53% of main stem channelized)
Mad (Klein, 1999)	California (485)	Hcut	Ins, Deg, φ9, Ar9, W8, ξ8, α9	Deg, W8, d8, Nrif9, RifL8	Still active
Lower Van Duzen (Klein , 1999)	California (426)			Deg, ξ8, W8, α9, d8	Still active
Lower Eel (Klein pers comm, 1999)	California (3113)			Deg, W8, ξ8, α9, d8	Still active
Griffre (58)	France (125)	Hcut	Deg	Ins, Deg6Agg (after mining stopped), W8 Bra6Step Pool, Str, Low Gradient	Aggrading areas still mined
Athi, Thwake, Kaiti, Muooni (65)	Kenya (N/r)		Agg	Ins, Deg, W8 (except Muooni ΔW=0)	Still active (extraction exceeds supply)
7 basins (19)	Alaska (<38.6)	Hcut, Deg (4 of 7), ξ8, P8	φ9, Ar9 (5 of 7)9, P8, Agg, d_{AVE}9	W8 & S8 (5 of 7), v9, Bra8, d_{AVE}9	1986-1996
13 basins (19)	Alaska (38.6 to 386)	Hcut (1 of 13), Deg (8 of 13), W8, P8 (1 of 13)	φ9 (4 of 13), d_{AVE}9, W8, Agg	d_{AVE}9, W8, W:d8, Q_S8 & S8 (8 of 13)	1996-1979

Table 2.3. Contd.

River (Ref.)	Location & CDA (mi^2)	Impact u/s of Mined Reach	Impact d/s of Mined Reach	Impact Within Mined Reach	Years Since Extraction
5 basins (19)	Alaska (>386)	Hcut (2 of 5), Deg (1 of 5)	Agg, d_{AVE}9	Q_S8, W8, W:d8,Q_S8 & S8 (1 of 5), Agg, d9	1997-1986

Redwood Ck (8)	California (278)	Hcut, Deg		Ins, Deg, Bars9, W:d8, Hom, Γ9	Active since 1987
Amite (27)	Louisiana (772)	W:d8	Deg initiated, W:d8, Ar9	Mea6Bra, Γ9, Ctf, W:d8	N/r (massive quantities extracted)
Humptulips & Wynoochee (7)	Oregon (N/r)			Ins, Deg, ΔW=0	N/r (Extraction exceeds supply)
Lower Manawata (7)	New England	Γ8, φ8	Γ8,φ9	Deg	Active
Cache Ck (7)	California (1150)	Nkp8, Deg	Bra, Shifting	Ins, Deg, W9, Q_{CAP}>Q_{MF}	Active
Lower Mackenzie (80)	Oregon (N/r)	Deg	Deg	Ins	N/r
Tujunga Wash (67, 80, 5)	California (115)	Nkpt8, Deg, W8		Ins, W8, Deg, d_P:d_R9	N/r

Legend

Agg=Aggrading
Ar9= armor decreasing
Avul=Avulsion
Bar9= erosion of bar forms
Bra8=Increase in braiding
Cf= meander cutoff
d8= increase in channel depth
d_{AVE}=average channel depth
Hcut=Headcutting
Hom=Homogenization of bed material
Q_{BFL}= flow with RI=1.5 years
Q_{CAP}= flow capacity at top-of-bank
Q_S8 =increase in sediment load
Nkp8= nickpoint migration
N/r=Not Reported
PoolL9 =Pool Length Decreasing
RB=Rock bed
RifL=Length of Riffle
S8=increase in gradient
ΔS=0 (no change in gradient)
Str=Straight
W9 = constricting
W:d9=width to depth ratio decreasing
ΔW=0 (no change in channel width)
α8 =increase in meander amplitude
Γ8=increase in sinuosity

AL=Alluvial
Ar8= armor increasing
Bar8=increase in bar formation
Bra=Braided
CDA=Catchment Drainage Area
d9 = decrease in channel depth
Deg=degrading
d_P:d_R9=loss of pool riffle definition
Geol=Geologic Control
Ins=Incised
Q_{INS}=flood of inset channel
Q_{MF}=maximum flood on record
Q_S9 =decrease in sediment load
Nrif=Number of Riffles
P=Wetted Perimeter
PoolL8 =Pool Length Increasing
RC=Rock controlled
RI=Recurrence Interval
S9=decrease in gradient
Sin=Sinuous
W8= widening
W:d8=width to depth ratio increasing
Win= winnowing
α9 =decrease in meander amplitude
Γ9 =straightening (decrease in sinuosity)
ξ8=increase in meander migration rate

$\lambda8$=increase in meander wavelength
$\varphi8$= increase in bed material size(coarsening)

$\lambda9$ =increase in meander wavelength
$\varphi9$=decrease in bed material size (fining)

2.2.2 Common Impacts Within Channel Segment Upstream of the Mined Reach

The observations reported for the channel segment upstream of the mined reach were the most consistent. Most case studies reported degradation of the bed of the river though the process of headcutting. Headcutting may be associated with an abrupt discontinuity in the bed (a nickpoint) or more simply an over steepening of the longitudinal gradient. The exceptions to this general finding were streams that limited headcutting due to structural or geologic controls. Other exceptions included channels located downstream of major flow control structures such as dams or urbanizing watersheds in which channel incision had already occurred. In the former case incision may be related to the "hungry water syndrom" while in the later case it may have been related to an increase in flow rate and volume.

2.2.3 Common Impacts Within Channel Segment Downstream of the Mined Reach

The incisement of the channel in both the zone of mining and the upstream segment may initiate a process of Valley Formation. This later process results in the formation of a new active channel and floodplain terrace inset within the original floodplain but at a lower elevation. As such Valley Formation results in severe property loss and the influx of large quantities of sediment to the channel system through degradation of the bed and bank collapse. The influx of sediment from the upstream channel segment may result in aggradation within the mined reach (as noted previously) and a concomitant loss of flow conveyance capacity. In many instances the flood hazard reduction benefits obtained through gravel extraction are more than offset by aggradation. Downstream of the extraction zone, sediment is deposited within the channel resulting in aggradation of the river bed and an associated loss in flow conveyance capacity. Aggradation also leads to river widening through bank erosion and plan form adjustment. Table 2.4 summarizes the reported morphological impacts in terms of aggradation or degradation for channels for which mining has been reported to be active or inactive.

Table 2.4. Case Studies Reporting Channel Aggradation or Degradation Relative To Current & Historic Mining Practices

State of Aggregate Extraction	Number of Case Studies Reporting AGGRADATION	Number of Case Studies Reporting DEGRADATION
Inactive	7	0
Active	1	5

It can be seen from Table 2.4 that the channel segments downstream of the mined reach have a tendency to aggrade once extraction within the zone of mining is terminated. As noted in Table 2.4, channels experiencing active gravel extraction tend to degrade in the downstream channel segment. This appears to hold whether the volume of material extracted exceeds supply or whether the coarse material is selectively removed within the mined reach resulting in a finning of bed materials. The reported impact as shown in Table 2.4 is channel degradation leading to incision, widening, and loss of bed armor.

Plan form adjustment tends to be more varied depending upon channel gradient and sediment composition relative to stream competence and capacity. There was insufficient information from the available case studies to draw any conclusions in this regard.

2.3 Discussion of the Morphological Adjustment Process

Gravel extraction for flood hazard reduction or for the commercial value of the aggregate differs little from conventional flood reduction measures when gravel extraction is undertaken at a large scale. Indeed the two management strategies are often linked. At a lessor scale gravel extraction can occur as an independent activity involving the removal of gravel bars through scalping (or skimming) on a periodic basis. On a larger scale gravel extraction can occur as instream pit mining (dredging) or floodplain mining. The skimming of gravel bars is the least intrusive of the mining activities while gravel mining through instream dredging has a greater impact on channel morphology. These activities can result in:

1) widening;
2) deepening;
3) straightening;
4) damage or removal of riparian vegetation;
5) loosening or destruction of sediment structures (imbricate forms);
6) the clearing of Large Woody Debris.

These activities mirror traditional flood mitigation strategies. Consequently, this discussion will deal with the two activities as if they were one and the same.

Pit mining within the floodplain typically becomes an issue when the channel erodes laterally and is captured by the pit resulting in channel avulsion. The morphological impact from these activities is not addressed in this study due to the random nature of the impacts and the lack of documentation.

The following Sub-Sections provide a discussion on the adjustment processes and modes of response as interpreted by the study team based on the literature review.

2.3.1 Channel Response Within the Mined Reach

The active channel in "stable" alluvial systems has been found to be in accord with flows of recurrence intervals of 1:1.5 to 1:2 years (Leopold et al., 1964)[2]. Gravel extraction and flood hazard reduction measures typically enlarged the active channel through lowering of the bed and widening of the banks. This has the effect of:

1) increasing bank height in the active channel;
2) disconnecting the floodplain from the active channel; and
3) increasing the conveyance capacity of the active channel.

The enlarged active channel may contain flows ranging from the 1:5 year to those in excess of the maximum flood on record. Consequently, the original active channel may have the conveyance capacity in excess of the original flood plain channel. The impact on stream power within the enlarged active channel is twofold:

a) during rare flood flow events unit stream power increases; while,
b) during flood flow events equal to or less then the 1:1.5 to 1:2 year flood, unit stream power initially decreases.

The former impact occurs because larger flood flows are contained within the enlarged active channel before they can spill out onto the original floodplain. The later impact occurs because the smaller flood flows are now spread out over a wider channel. Recall that the mid-bankfull to bankfull flow events transport the most sediment and therefore, are responsible for the formation of the active channel. In an in-regime channel system, the dimensions of the active channel represent a balance between the forces exerted on the boundary by these flow events and the resistance of the boundary materials. This balance has been upset with two principle effects:

i) the frequent flood flows (mid-bankfull to bankfull flow) may no longer be able to move the larger particles previously transported by the stream at these flows; and,
ii) the rare flood flows may be able to scour the boundary materials within the enlarged active channel and cause catastrophic failure resulting in channel avulsion.

The above scenario is complicated by other factors associated with instream works including:

1. Removal of Large Woody Debris (LWD) from the channel;
2. Modification or removal of riparian vegetation;
3. Removal of aquatic vegetation;
4. Armoring of the bank materials with cobbles and boulders from the channel bed;
5. The destruction of imbricate sediment structures and the loosening of previously embedded materials; and,
6. The alteration of form roughness associated with the straightening of the channel and the loss of pool-riffle definition.

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[2] Leopold, L.B.,Wolman M.G. and Miller, J.P. (1964). "Fluvial Processes in Geomorphology," W.H. Freeman and Co., San Francisco. 522 pp.

In those instances where the sediment transport potential remains sufficient to transport the sediment load, at mid-bankfull to bankfull flow, an erosional environment may dominate. Bed degradation is the most commonly reported initial response. Where the sediment transport potential is not sufficient to transport the sediment load at these flow rates the stream may drop its sediment load within the previously mined reach. In the former case the channel may continue to incise thereby increasing the flow conveyance capacity of the channel even after cessation of mining operations. If the channel was not already straight or straightened during the "maintenance" program, it will have a tendency to straighten thereby increasing channel slope and unit stream power. The increase in slope may be partially or completely offset, however, by the decrease in bed elevation through incision. Never-the-less, the higher flow capacity of the enlarged active channel will tend to increase stream power for rare flood flow events and the potential for scour of the bed and banks.

Incision of the bed also increases the height of the banks of the enlarged active channel. The banks may also be susceptible to basal scour resulting in an oversteepened state and an increase in the potential for bank failure. The bed armor that may have been placed on the banks is now suspended above the point of secondary maximum boundary shear stress near the bank toe. Failure of the banks, the second most common observation, tends to widen the channel. This has two major consequences:

a) an increase in channel width (W) further increases channel flow conveyance capacity; and,
b) the bank materials may represent a major influx of sediment.

Once again the additional enlargement of the already enlarged active channel affects unit stream power. Unit stream power increases yet more for rare flood flow events but decreases for mid-bankfull to bankfull events with the increase in channel width. If the sediment transport potential is sufficient to transport the sediment load despite the increase in channel width, then degrading conditions may continue until the channel has widened or lost sufficient slope to arrest the downcutting process. If the stream is no longer capable of moving its sediment load then sedimentary processes may dominate.

Within the sedimentary dominated environment the initial response is homogenization of the bed materials (if not already homogenized through instream mining activities) and infilling of the pools (if not previously destroyed). As a result the pool sections tend to become less well defined and shorter, while riffles extend in length. Excessive aggradation may completely bury the pools resulting in a long riffle or run. Consequently, the number of riffles decline while the length of riffles increases.

In the second stage of adjustment, the river's predisposition to concentrate flow results in the development of bar heads (incipient bar forms). This leads to deposition of materials in low bed shear stress regions eventually resulting in an alternating pattern of sediment bars. These bar forms can become massive over several to tens of years after cessation of mining operations if stream capacity and competence is less than the supply of material. Where stream competence and capacity remain relatively high the concentration of flows may also occur but through different processes. The loosened bed materials are susceptible to winnowing. The loss of fines that comprise the matrix within which the coarser materials are found can cause slumping of the coarser particles leaving a depression within which the flows may concentrate. This region of concentrated flow is described as an inset channel. In the sedimentation environment the continued development of the bar forms may also result in the constriction of flow area and the formation of an inset channel. Consequently, both erosional and depositional environments can result in the formation of an inset channel.

The concentration of flows within the inset channel due to the formation of bars has two primary effects:

i) The upper portion of the bars may become vegetated with wood species and stabilized as part of the development of a new flood plain; and,
ii) The toe of the bars may deflect flow into the opposite bank.

The concentration of flows within the enlarged channel and the deflection of flows against the banks opposite the bar forms increases the channels ability to erode its boundary. The channel may respond by re-initiating the downcutting process, tend to widen or both downcut and widen depending upon the absolute resistance of the bed and bank materials and their relative resistance one from the other. If downcutting dominates the channel will repeat the above steps until:

1) the channel slope has been reduced or channel width has increased to the point where unit stream power is insufficient to erode the bed;
2) the channel erodes into a more resistance stratigraphic unit; or,
3) the bed becomes armored.

Following completion of the adjustment phase involving high rates of downcutting, the sedimentary environment is re-established. The formation of bars re-occurs and the channel may re-initiate attack on its banks through basal scour. This process leads to oversteepening and eventual collapse of the destabilized banks. The influx of bank materials and sediments derived from upstream sources may aggravate the lateral instability of the channel. The development of the inset channel through cross-sectional and plan form adjustments will continue until the inset channel is capable of moving its sediment load while maintaining its hydraulic geometry. The new inset channel has a bankfull width that is significantly smaller then that of the former active channel after it was initially enlarged. At this point the inset channel represents the new active channel and the former active channel represents an incipient floodplain channel. The incipient floodplain channel, however, may be too narrow resulting in an entrenched system. Depending upon channel slope and the nature of the bed and bank materials the new active channel may begin to re-meander expanding the incipient floodplain. The result is a new active-floodplain channel system at a lower elevation inset into the original floodplain. This process is referred to as “Valley Formation”.

The above process can be accelerated by catastrophic failure of the system during a rare flood flow event. The increase in bank height associated with channel deepening and the increase in flood flow conveyance capacity make the enlarged channel more susceptible to catastrophic failure. During a rare flood flow event failure of the banks can result in:

a) avulsion (realignment of the channel);
b) degradation of the bed;
c) the formation and rapid upstream migration of nickpoints;
d) large scale bank failure; and,
e) the movement of elevated quantities of sediment into the channel system.

The sediment introduced to the channel or freed from instream storage locations (e.g. sediments trapped behind Large Woody Debris or boulders upstream of the mined reach) during rare flood flow events represent a further complication to the above response scenario. The materials tends to move downstream at different rates depending upon particle size and shape. Smaller materials may be flushed through the system rapidly while coarser material may move through the system during mid-bankfull to bankfull events by traveling from one riffle to the next. Consequently, these materials can take years to be flushed through the channel system. Still larger material may remain as bed armor until moved during a rare flood flow event. Once the supply of these materials has been exhausted and these sediment waves have passed through the subject reach the sediment regime may return to pre-disturbance conditions. If the change in sediment regime is significant relative to stream competence and capacity to move its sediment load, then this alteration in the driving mechanisms must also be addressed.

2.3.2 Channel Response Upstream of the Mined Reach

The process of downcutting within the mined reach creates a discontinuity in the bed profile. In some instances the discontinuity is abrupt and it resembles the riser in a staircase. This form of discontinuity is referred to as a nickpoint (also known as niche point and knickpoint point). Other discontinuities are more gradual. However, both types cause acceleration and de-acceleration of the flow as it passes over the discontinuity. The change in flow hydraulics increases scour potential on the bed. If the bed materials are susceptible to movement under these conditions the discontinuity may migrate headward. As the discontinuity progresses upstream it results in a lowering of the bed and channel incision. This may initiate a process of “valley formation” in which the channel forms a new active and flood plain channel system within the existing valley, but at a lower elevation as noted for the mined reach.

The process of Valley Formation introduces large quantities of sediment into the channel through erosion of the bed and collapse of the banks. The influx of sediment may induce or aggravate aggrading conditions in the downstream reaches. Headcutting of the discontinuity may continue until:

a) the headcut encounters a structural or geologic control point; or,
b) the break of slope created by the discontinuity diminishes to a point where it is no longer morphologically significant.

In many instances the influx of sediment to the mined reach exceeds the amount of material extracted or conveyed downstream. Particulary after cessation of the mining operations. When combined with a loss in channel gradient associated with channel downcutting through mining activities, the flood conveyance capacity within the mined reach may actually decline. The result is an unstable channel form, property loss and loss of flow conveyance capacity within the mined reach. These Impacts are contrary to the intent of the “maintenance” works. Further, the “maintenance” activities negatively impact the reach upstream of the mined segment through accelerated property loss.

2.3.3 Channel Response Downstream of the Mined Reach

The process of valley formation results in the influx of massive quantities of sediment into the channel system. Much of this material is transported downstream, contributing to aggradation within the downstream reaches. Aggrading conditions result in:

1) a net decrease in flow depth;
2) the loss of sediment transport potential;

These effects may lead to a variety of possible morphological impacts including:

a) the formation of massive bar deposits;
b) the siltation of pools:
c) the formation of chutes;
d) more frequent overbank flows;
e) the formation of cutoff channels;
f) the initiation of meander development;
g) accelerated meander propagation;
h) the development of a braided or multiple thread channels systems;
i) the loss of pool-riffle definition;
j) channel widening;
k) channel straightening;
l) increased sediment deposition in the riparian zone;
m) shortening of pools; and,
n) an increase in riffle length.

The exact impacts are a function of stream competence and capacity relative to the alteration in the sediment regime. If the channel is unable to move its sediment load then sedimentary processes dominate channel response as noted above. This is the most commonly documented response mode following cessation of gravel mining operations.

While gravel mining is still active an erosional environment may dominate as noted previously. The primary impacts are:

1) a loss of coarse material through gravel extraction;
2) the reduction in sediment mass being supplied to the downstream reach; and,
3) a net increase in sediment competence and capacity

These impacts may have the following morphological affects:
a) a fining of the bed material;
b) degradation of the bed resulting in channel incision
c) an increase in meander propagation rate;
d) channel widening through basal scour;
e) channel straightening;
f) an increase in channel gradient; and,
g) a decrease in channel sinuosity.

The exact combination of impacts depends upon the sediment characteristics relative to the competence and capacity of the channel system, the type of channel system, and other extraneous factors.

SECTION 3.0 CONCEPTUAL MORPHOLOGICAL RESPONSE MODEL

3.1 Model Rationale and Development

The ability to predict channel response and ultimate channel form from an existing or proposed disturbance represents a powerful tool to practioners and decision makers. Such a tool could provide:

A) a systematic basis for the design and costing of restoration programs;
B) the development of prioritization algorithms; and,
C) the development of conditions required for approval of proposed gravel extraction and flood hazard mitigation projects.

Given the complexity of fluvial systems it should be understood that the proposed model represents a first attempt at developing such a tool. Further development and refinement of the proposed model will be required. Never-the-less, it is believed that the model as proposed provides the conceptual framework for the development of such a tool.

In developing the proposed model a number of critical factors identified in the literature review were considered as noted in the following Sub-Sections.

3.3.1 Watershed Scale

The literature review established a link between watershed size and channel sensitivity to a disturbance associated with gravel extraction. The morphological response of large watersheds wherein CDA>386 mi^2 (1000 km^2) were less sensitive to gravel extraction practices then channels within small watersheds (CDA<38.6 mi^2 (100 km^2)). Most Vermont rivers fall within the small to intermediate size range and consequently, should be considered to be sensitive to very sensitive to morphological impacts associated with gravel extraction activities. In development of the proposed model the focus was on these smaller scale systems. The model structure, however, is robust in that it is independent on absolute scale but sensitive to relative scale. That is a small quantity of gravel extraction in a small system would have the same impacts as a large scale operation on a proportionately larger river, all other factors being equal. Consequently, the impact and subsequent morphological response is determined by the magnitude of the disturbance relative to the ability of the channel to absorb the disturbance.

3.3.2 Stream Type

The literature review noted that streams of differing morphology also demonstrated different degrees of sensitivity to a disturbance. Braided streams were found to be the least sensitive while straight channels were considered to be the most sensitive. Vermont streams are typically straight or meandering systems. The proposed model was developed for application to these later channel systems with bed materials ranging from gravel in a silty sand matrix to cobble or small boulders in a sandy gravel matrix. However, the model may be extended to include braided channels.

3.3.3 Reach Location

According to the literature review different morphological responses were observed within, upstream and downstream of the mined segment. The model was structured to apply to any segment regardless of its location relative to the mined reach, provided the initial disturbance is known.

3.3.4 Status of Mining Operation

Impacts on the channel in both the mined reach and the channel segment downstream of the zone of mining were influenced by the status of mining operations. Depositional environments dominated in channel systems where gravel extraction operations were no longer active. In contrast, erosional environments may dominate if mining operations are still active. The model was structured to address both depositional and erosional environments.

3.2 Proposed Model Structure and Organization

The proposed model consists of 39 modules with each module representing a specific set of parameters, processes or impacts as summarized in Table 3.1. The modules are interconnected such that the impact associated with the alteration of a parameter in one module can be transferred to other inter-related stream parameters and processes represented in other modules. Figure 3.1 illustrates the organization of the model, which begins at module 1A labeled START and finishes in module 32 depending on the outcome. The proposed model is presented in Appendix B.

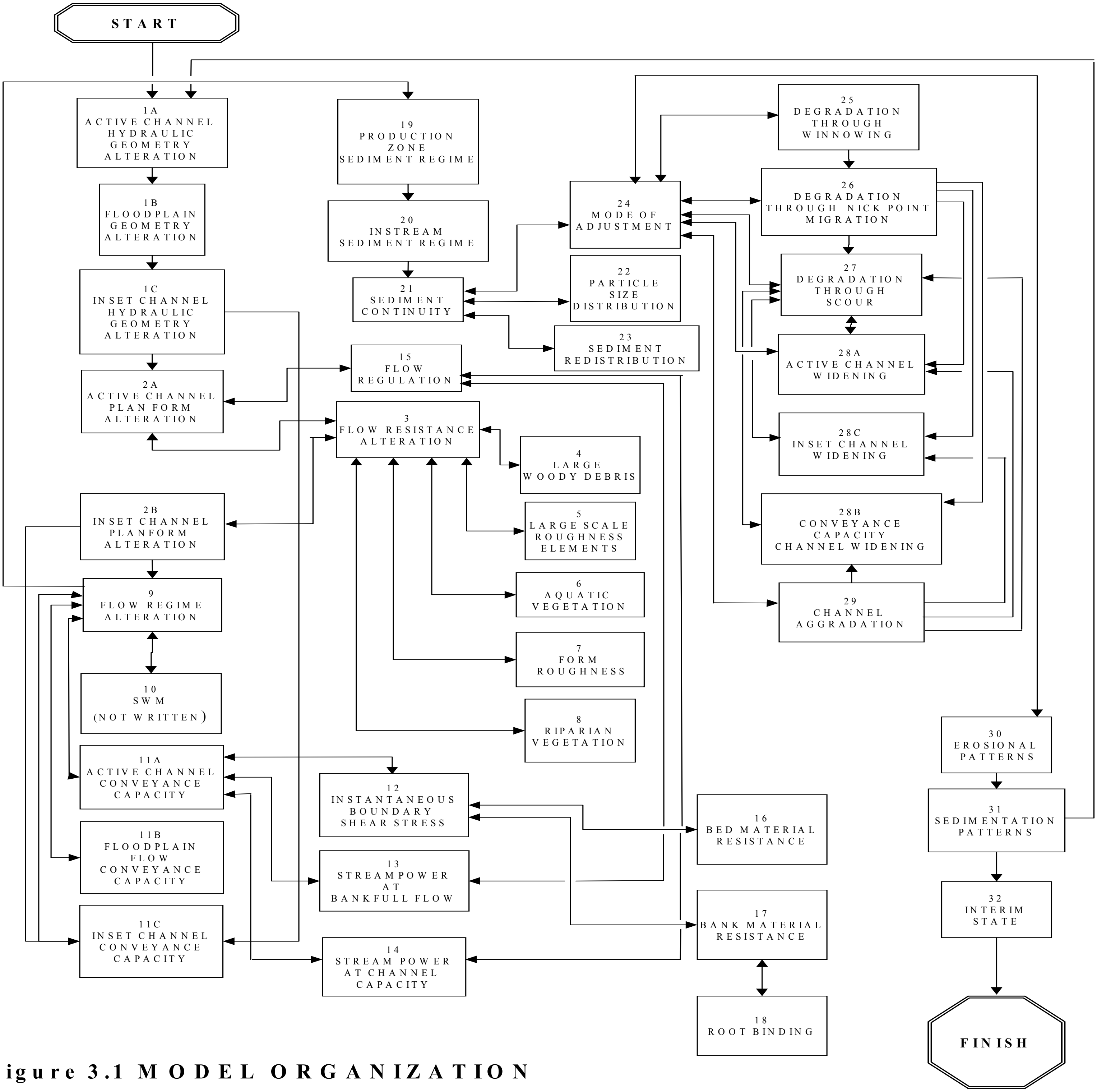

Figure 3.1 MODEL ORGANIZATION

Figure 3.1 Model Organization

Table 3.1 Summary of Module Function and Process

MODULE		**PARAMETERS OR PROCESS**
No.:	**TITLE**	
1A	Active Channel Hydraulic Geometry Alteration	Change in cross-section dimensions of the active channel at bankfull stage (W_{BFL}, d_{BFL}, A_{BFL})
1B	Floodplain Channel Alteration	Change in floodplain cross-section at inundation of the riparian zone (W_{CAP}, d_{CAP}, A_{CAP})
1C	Inset Channel Hydraulic Geometry Alteration	Change in cross-section dimensions of the inset channel at top-of-bank (W_{INS}, d_{INS}, A_{INS})
2A	Active Channel Plan Form Alteration	Change in plan form parameters for the active channel ($ELEV_{BFL}$, S_{BFL}, L_{BFL}, Γ_{BFL})
2B	Inset Channel Plan Form Alteration	Change in plan form parameters for the inset channel ($ELEV_{INS}$, S_{INS}, L_{INS}, Γ_{INS})
3	Flow Resistance Alteration	The net change in flow resistance within the active channel (n)
4	Large Woody Debris	Change in flow resistance associated with removal or modification of Large Woody Debris in the active channel (n_{LWD}, FLWD, NLWD, CNLWD, W_B)
5	Large Scale Roughness Elements	Change in flow resistance associated with removal or modification of large inorganic roughness elements (n_{LSRE}, NLSRE, ϕ_{84}, ϕ_i)
6	Aquatic Vegetation	Change in flow resistance associated with removal or modification of aquatic vegetation (n_{AVEG}, A_{EFF})
7	Form Roughness	Change in flow resistance associated with alteration in channel form (n_{FORM}, S_{EFF})
8	Riparian Vegetation	Change in flow resistance associated with modification or removal of riparian vegetation (v, n_{RVEG})
9	Flow Regime	Change in the flow regime due to the alteration of land use type or land use practices (TIMP, Q_{POST}, Q_{PRE})
10	Stormwater Management	Change in the flow regime due to Stormwater Management Practices (not written)
11A	Active Channel Conveyance Capacity	Change in the flow conveyance capacity of the active channel at top-of-bank (Q_{ACT}, Q_{BFL})
11B	Floodplain Channel Flow Conveyance Capacity	Change in the flow conveyance capacity of the floodplain channel (Q_{CAP}, Q_{RIP})
11C	Inset Channel Flow Conveyance Capacity	Change in the flow conveyance capacity of the inset channel (Q_{INS})
12	Instantaneous Boundary Shear Stress	Change in the magnitude and distribution of instantaneous boundary shear stress at bankfull stage and top-of-bank at channel capacity on the bed and least resistant bank (β_S, $[(\tau_o)_{BED}]_{BFL}$, $[(\tau_o)_{BNK}]_{BFL}$, $[(\tau_o)_{BED}]_{CAP}$, $[(\tau_o)_{BNK}]_{CAP}$,

13	Stream Power at Bankfull Flow	Change in stream power and unit stream power at bankfull stage $(\Omega_{BFL}, \omega_{BFL})$
14	Stream Power at Channel Capacity	Change in stream power and unit stream power at top-of-bank at channel capacity $(\Omega_{CAP}, \omega_{CAP})$
15	Flow Regulation	Change in flow regime associated with dams, bridges, weirs or other hydraulic control structures (not written)
16	Bed Material Resistance	Change in bed material resistance associated with the alteration in material composition, distribution or structure $([(\tau_{CRT})_{BED}]_{\phi 84}, \{[(\tau_o-\tau_{CRT})_{BED}]_{BFL}\}_{\phi 84}, \{[(\tau_o-\tau_{CRT})_{BED}]_{CAP}\}_{\phi 84})$
17	Bank Material Resistance	Change in bank material resistance associated with modification of bank materials, bank height or riparian vegetation at bankfull stage and channel capacity at top-of-bank $((\tau_{CRT})_{BNK}, [(\tau_o-\tau_{CRT})_{BED}]_{BNK}, [(\tau_o-\tau_{CRT})_{BNK}]_{CAP})$
18	Root Binding	Change in bank material resistance due to alteration in riparian vegetation (H)
19	Production Zone Sediment Regime	Change in sediment production (mass), timing or physical characteristics from land areas outside of the riparian zone $((Q_S)_{PROD}, \phi_{50})$
20	Instream Sediment Regime	Change in the production (mass), timing or physical characteristics of sediment generated from within the riparian zone $((Q_S)_{INST}, (Q_S)_{BNK}, (Q_S)_{BED})$
21	Sediment Continuity	Change in the balance between the influx and output of sediment from the subject reach $((Q_S)_{IN}, (Q_S)_{OUT}, \phi_{CRT}, (\phi_{CRT})_{BFL}, (\phi_{CRT})_{CAP})$
22	Particle Size Distribution	Change in sediment gradation $(\xi, (\phi_{16}), (\phi_{50}))$
23	Sediment Redistribution	Change in sediment patterns and distribution
24	Mode of Adjustment	Adjustment of channel form through degradation, channel widening, aggradation and plan form adjustment
25	Degradation Through Winnowing	Sediment sorting and selective removal of fines leading to slumping of bed materials and uniform gradation
26	Degradation Through Nickpoint Migration	Formation of an inset channel and adjustment of channel hydraulic geometry and longitudinal channel slope associated with nickpoint migration
27	Degradation Through Scour	Change in hydraulic geometry and longitudinal channel slope associated with bed scour
28A	Channel Widening: Active Channel	Change in the width of the active channel at bankfull stage
28B	Channel Widening: Conveyance Capacity Channel	Change in channel width at top-of-bank for the floodplain channel
28C	Channel Widening: Inset Channel	Change in channel width at the depth of the inset channel
29	Channel Aggradation	Change in hydraulic geometry due to the build up of sediments on the bed

30	Erosional Patterns	Adjustment of plan and cross-sectional form associated with widening or degradation
31	Sedimentation Patterns	Adjustment of plan and cross-sectional associated form associated with aggradation
32	Interim State	Check for metastable equilibrium condition

The modules consists of a series of *questions*, *statements*, *"go tos", gates, returns,* and *finish boxes (using shaded boxes an example of each is labeled in Fig. 3.2)*. The *question* and *statement boxes* contain a question or statement respectively to which the user is required to provide either a "yes" or "no" response. Depending upon the decision the user proceeds through either the"yes" or "no" *gate* to the next *box*. The procedure is repeated until the last module is completed. Depending upon the answers provided in the last module the user is advised that the morphological response is incomplete and another iteration is required or that the interim adjusted morphology has been achieved and the modeling is terminated. Examples of the module content and format are provided in Figures 3.2 and 3.3 (Module 30 Erosional Patterns and Module 31 Sedimentation Patterns respectively).

Criteria for the "yes" or "no" responses are provided where possible. Unfortunately, stream channel behavior is only understood in a probabilistic manner and rigorous quantitative criteria can not be provided for each *box*. Where quantitative criteria can not be provided an effort has been made to provide guidelines to assist the decision making process. Despite attempts to provide criteria and guidelines there remain instances where professional judgement is required. Although it is not currently possible to eliminate the reliance on professional judgement, the number of these occasions where judgement is required may be reduced through further development of the proposed model.

As with any model the better the channel system is understood the better the modeling effort. However, detailed quantitative measurements of channel morphology are not required for application of the proposed model. Some knowledge or first order approximations of channel hydraulic geometry and plan form parameters, bed and bank material composition, channel roughness attributes and riparian vegetation are necessary. In this regard the completion of a Rapid Geomorphic Assessment form (or the equivalent) by an experienced geomorphologist in combination with chain and hand level measurements of channel dimensions and longitudinal profile are recommended. It is also necessary to have a good understanding of the type and magnitude of the initial disturbance.

The initial disturbance pertains to the alteration in channel morphology and sediment, riparian vegetation structures within the mined segment of the reach of interest. The propagation of the morphological impacts from this initial disturbance within the mined reach represent the initial impacts in the downstream and upstream reaches respectively. In using the model the user should start with the mined reach and complete the first iteration to determine the nature of the morphological impacts relevant to the upstream and downstream segments. The model should then be applied to the upstream segment and subsequently to the downstream segment. The impacts on the upstream reach represent a potential alteration to the driving mechanisms within the mined reach. Consequently, the second iteration of the model through the mined reach must account for alteration in flow and sediment inputs from the upstream segment. The process is repeated until a new quasi-equilibrium condition is achieved in each of the reaches.

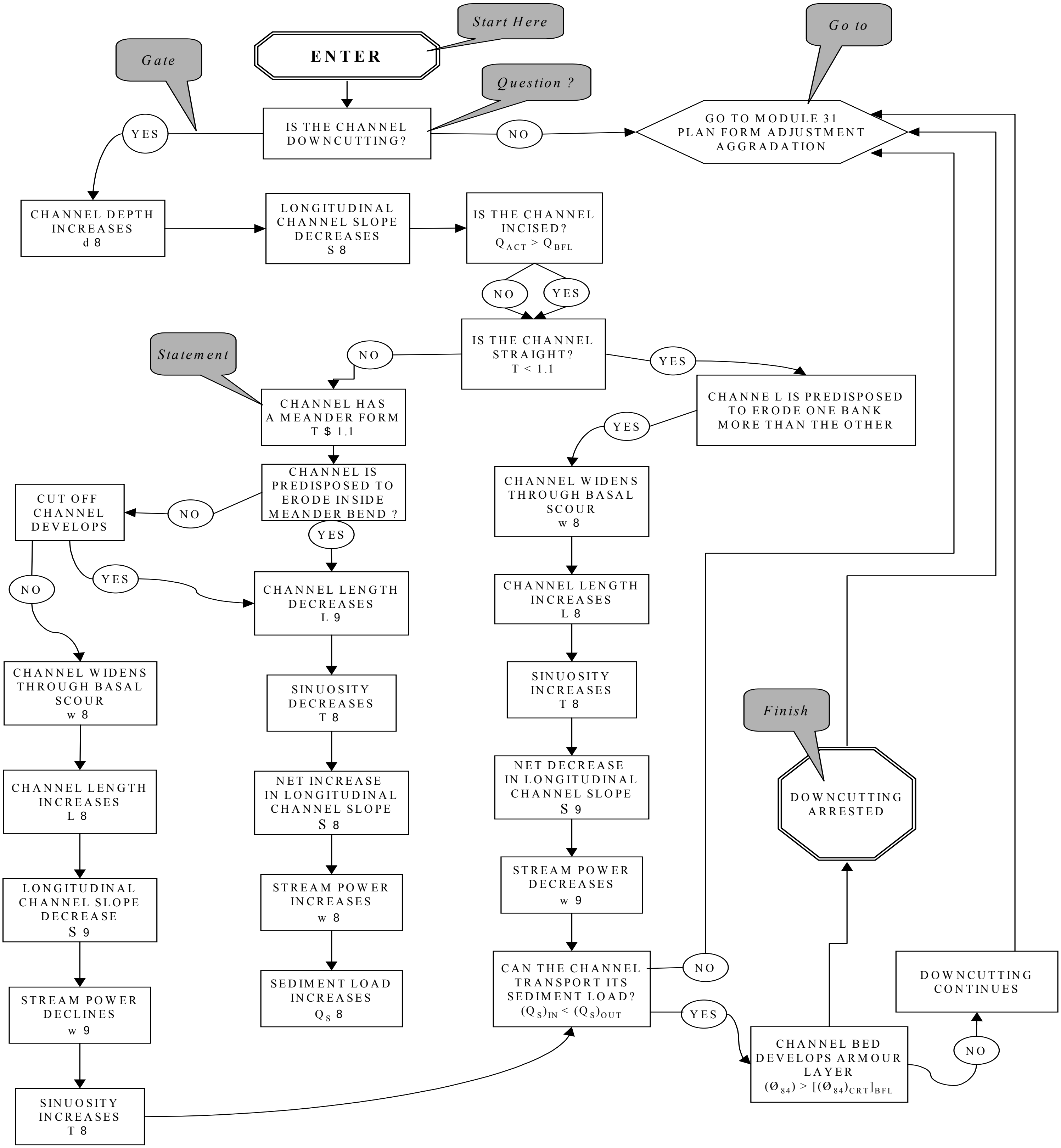

Figure 3.2 MODULE 30 EROSIONAL PATTERNS

Figure 3.2 Module 30 Erosional Patterns

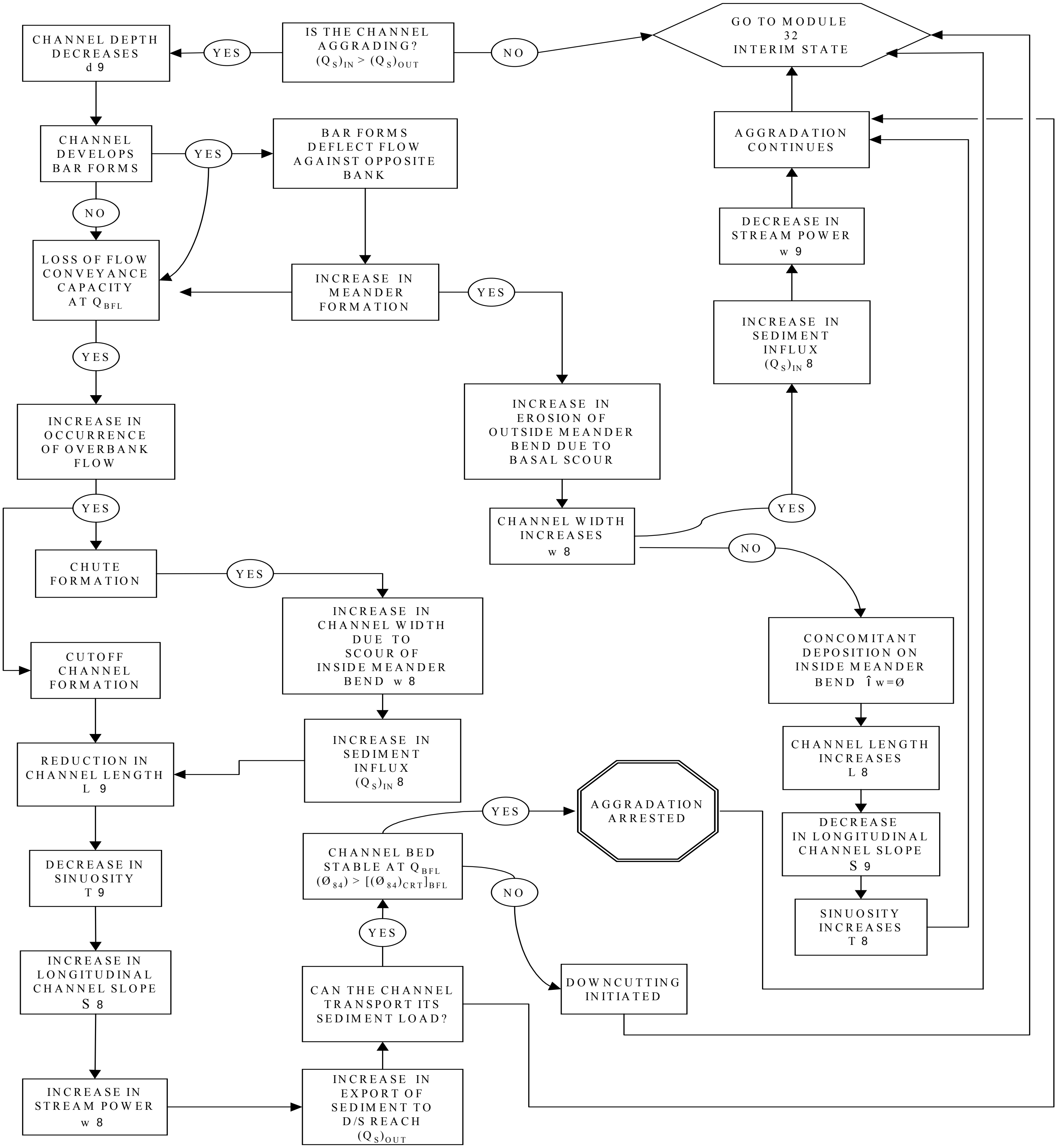

Figure 3.3 MODULE 31 SEDIMENTATION PATTERNS

Figure 3.3 Module 31 Sedimentation Patterns

SECTION 4.0
CASE STUDY

4.1 Introduction

The morphological impacts and adjustment processes summarized above may take tens to hundreds of years to complete. During this period of time a myriad of impacts may occur from both natural and anthropogenic causes. Given the length of the adjustment process the morphological impacts from any specific disturbance may be superimposed on another disturbance. This likelihood increases as the relaxation time of the morphological parameter increases. For example, sedimentary forms such as imbricate structures can form in time periods of 10^{-1} to 10^{0} years following a disturbance. Hydraulic geometry variables such as bankfull channel width may require 10^{1} years to adjust to a disturbance, while macroforms such as meander wavelength may require 10^{2} to 10^{3} years to come to a new equilibrium position. Consequently, cause and effect relationships may not be readily apparent at any point in time. One method of dealing with these complexities is to adopt a pairwise comparison approach and to study the subject channel system relative to a reference channel system through time. In the pairwise approach the subject channel is selected to represent a channel system that has been significantly altered through anthropogenic inputs over a reference period. A second channel system is one that has experienced perturbations primarily through natural causes such that anthropogenic factors may be ignored (the baseline or reference channel). The two systems must be of similar size, basin morphology, aspect, climate, land use, topography and geologic condition. Using this approach the complex array of naturally induced impacts are incorporated into the assessment and differences between the subject and reference channel systems may be interpreted as being caused by anthropogenic factors.

The second component of this approach is the study of the two channel systems through time. A sufficient time period being decades for hydraulic geometry parameters, to centuries for macroforms as noted above. The time period also depends upon the nature and magnitude of the disturbance and the sensitivity of the channel system to alteration. Channels formed in loose sandy materials respond more rapidly than channels formed in stiff, cohesive materials. Such periods of detailed morphological observation are seldom available. Consequently, alternative methods must be used to study stream behavior through time. The analysis of aerial photography is one means of obtaining an historical perspective. Photographs taken of the channel at various times can be digitized, adjusted for differences in scale and overlain to determine the shifts in channel plan form location and channel width within the subject reach. If enough time periods are assessed in this manner then this information can also be used to determine rates of change through time. The same analysis approach is applied to both the "reference" and "subject" channel systems. This approach was adopted for this study.

4.2 Selection of Study Channels

The White River (CDA=21.8 mi^2) through the Town of Granville from the Bowl Mill Bridge to the first crossing of Route 100 (the Farr property) was selected as the “subject” reach (Figure 4.1). The River drains the Green Mountain Forest Reserve through the main branch and Alder Meadow Brook a major tributary. The upper portion of the White River through the Town of Granville has been widened and deepened on at least four occasions since 1938 through the implementation of flood hazard mitigation measures. Although the tributary area has been altered through deforestation and grazing dating back to the early to mid 1800's, the watershed has been reforested with no significant land use alterations since the early 1900's. A more detailed discussion of the land use history within the subject watershed is provided in Appendix C.

The channel system has also experienced three major flood flow events (see Appendix C). However, after each event the channel was enlarged through “maintenance” activities as noted above. Consequent, anthropogenic activity is considered to be the primary factor in the alteration of channel morphology within the “subject” reach.

The West Branch of the Tweed River in Pittsfield was selected as a reference reach because intrusive management is understood to be minimal. The “reference” reach is also within the Green Mountain range and a tributary of the White River. It’s watershed area (CDA=17.7 mi^2) is also similar to that of the “subject” reach.

4.3 Aerial Photography Analysis

4.3.1 Methodology

Aerial photographs for the towns of Granville and Pittsfield Vermont were analyzed using Idrisi version 2.0 Geographical Information System (GIS) and Cartalinx version 1.0 software. Air photos for the years 1939, 1962, 1974 for each town were obtained from the Agency of Natural Resources and digital orthophotos for the year 1995 were purchased from the Vermont Mapping Program.

The photos were used to determine hydraulic geometry and plan form parameter values for the active channel along a segment of the White River in Granville and the “reference” reach on the West Branch of the Tweed River in Pittsfield for each epoch. The parameters assessed were:

i) active channel cross-sectional width (W_{ACT});
ii) average normal shift (ξ_{NAVE});
iii) maximum normal shift (ξ_{NMAX});
iv) thalweg length (L_{THA}); and,
v) reach surface area $A_R=(W_{ACT})L_{ACT}$ in which L_{ACT} represents the length of the active channel.

The normal shift is defined as the distance of movement of the stream channel measured perpendicular to the channel centerline. Average normal shift was determine at 65.6 ft (20 m) intervals along the channel. Maximum normal shift was determined for points located on outside meander bends.

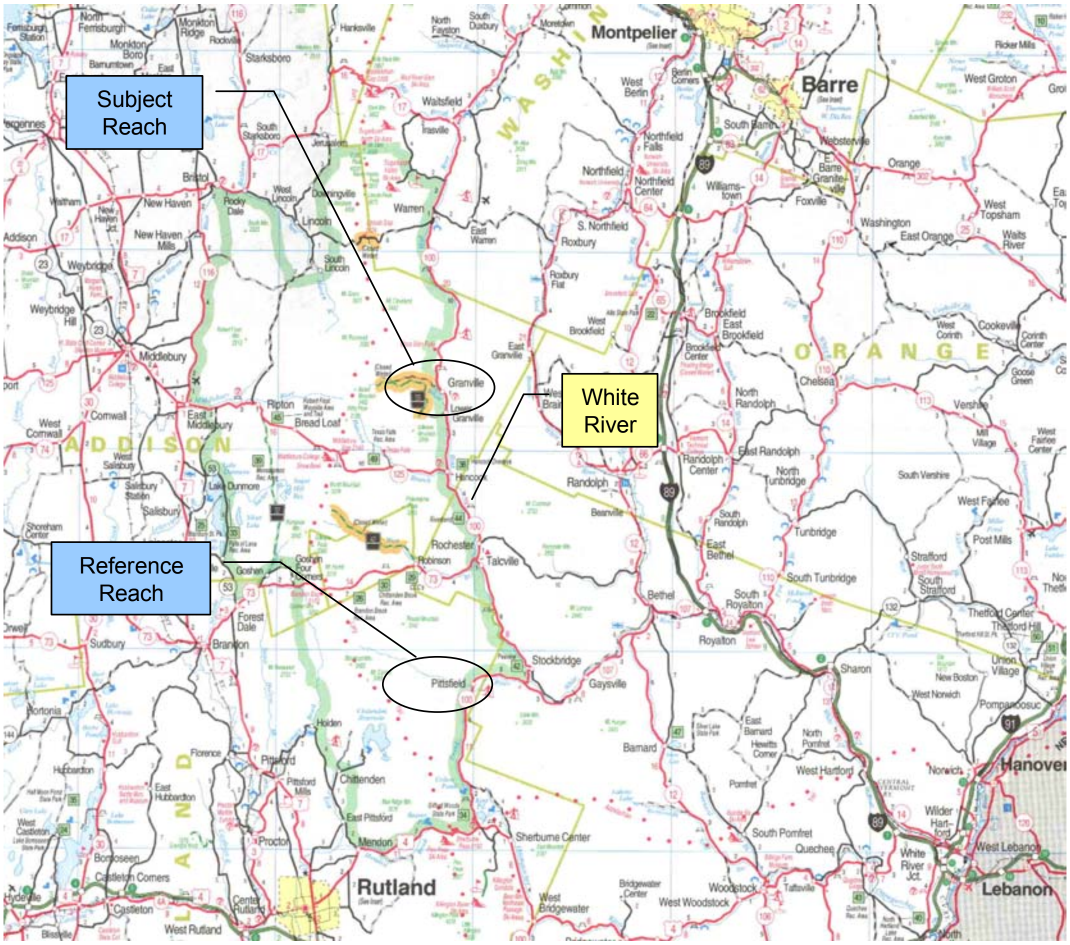
Subject Reach
White River
Reference Reach
Montpelier
Barre
Granville
Pittsfield
Rochester
Hancock
Randolph
Bethel
Rutland
Middlebury
Hanover
Lebanon
ADDISON
ORANGE
WASHINGTON
RUTLAND

Figure 4.1

In addition to these parameters the presence of stream features (bars, inset channels and evidence of mining) were also noted. These data were used to determine changes in plan form and hydraulic geometry for the active channel for the “subject” and “reference” reaches. The parameter values and changes in parameter values were then compared between the “subject” and “reference” reaches as the basis for determination of the impact of in-stream works and gravel mining on channel form.

Figure 4.1 Location Map For Subject (White River Through Granville) & Reference Reach (West Branch of The Tweed River Near Pittsfield)

4.3.2 Procedure

The scale of each airphoto was estimated by measuring features on the airphoto and comparing the features to the same distance on 1:24,000 USGS topographical maps. Using this method the scales of the 1939, 1962 and 1974 airphotos were estimated to be 1:35,000, 1:20,000 and 1:20,000 respectively. Based on these approximate scales, a suitable scanning resolution was chosen and this resulted in airphoto images of similar resolution. Each of the airphotos were scanned using a high (true optical) resolution flat bed scanner, resulting in a digital image for each year.

The digital airphotos were then imported into Idrisi so that they could be spatially georeferenced to a known position on the ground. A ground control survey was carried out to locate identified features (houses, barns, etc.) common to all four years of airphotos. The control points were surveyed and recorded in State Plane Coordinate NAD 83 (spc83vt1). Through Idrisi's *resample* function a georectification procedure was used to correct all images to the new reference system.

The *resample* procedure results in a set of georectified airphoto images that are in the same reference system and at the same scale. The channel centerline derived from the 1939, 1962, 1974 and 1995 images are overlain on the 1995 images in Figures 4.2 to 4.3 for the White River and West Branch of the Tweed River respectively. The georectified images were used to digitize stream features, and determine changes in hydraulic geometry and plan form adjustment. The river channel reaches were digitized and overlaid for comparison. The digitized reaches were also used to estimate total reach area (A_{ACT}) for each year. The areas of channel shift were identified and digitized to obtain measures of normal shift[1]. Each reach was digitized at intervals of 65.6 ft (20 m) perpendicular to the stream to measure active channel width (W_{ACT})and calculate an average width. Finally an approximation of the thalweg was digitized for each reach and year, resulting in an estimate of total reach length (L_{THA}) and change over time.

4.4 Assessment of Morphological Response

The White River through the study area was divided into three segments:

A) Reach 1 represents the reach upstream of the mined reach. The upstream reach is a steep gradient, step-pool, rock controlled channel system. Morphological impacts through this reach were prevented due to geologic control of headcutting. Consequently, this reach was not considered in the aerial photo analysis.

B) Reach 2 is the reach representing the zone of gravel extraction. This reach runs from the Bowl Mill Bridge to a point approximately 2228 ft (679 m) downstream of the Bridge. This represents the 1973 limit of gravel extraction and flood hazard mitigation works. The last series of photographs were taken in 1995 prior to the 1998 flood and subsequent flood remediation works.

Figure 4.2 Georectified Airphoto Image for the White River Through the Town of Granville (1974): Channel Centerline for 1939, 1962, 1974 and 1995 Aerial Photographs

Figure 4.3 Georectified Airphoto Image for the West Branch of the Tweed River Near Pittsfield (1962): Channel Centerline for 1939, 1962, 1974 and 1995 Aerial Photographs

C) Reach 3 represents that segment of the channel downstream of the mined reach (length of reach

3386 ft (1,032 m). This channel segment runs from the downstream limit of Reach 2 to the first crossing of Route 100. Although primarily alluvial, a short section of the lower portion of this reach is worn into bedrock. The bedrock forms a geologic control on downcutting. Further, several sections within the lower half of this reach with been trained using rip rap and log cribs. Consequently, a sub-reach within Reach 3 beginning at the downstream end of Reach 2 and progressing to a point 1476 ft (450 m) was selected for the analysis.

A summary of the occurrence of major flood flows, maintenance activity, dates of aerial photographic coverage and land use history are provided in Table 4.1. Four major flood events have been reported since 1927 along with four known and one possible occurrence of maintenance activity.

Table 4.1 Summary of Flood, Land Use and Channel Maintenance History and Aerial Photographic Coverage of the White River Through Granville.

Period	Year of Major Flood Flow Event	Year of Channel Maintenance	Year of Aerial Photography	Land Use History
1830-1869				Settlement of Granville area -construction of mills and dams on the White River - logging and grazing
1870-1909				Decline in logging & grazing leading to reforestation
1910-1929	1927	1927*		Logging and grazing marginal or discontinued
1930-1939	1938	1938	1939	Decommissioning of last dam upstream of Granville
1940-1949				Forested basin with marginal logging and grazing
1950-1959		1957		
1960-1969			1962	
1970-1979	1973	1973	1974	
1980-1989				
1990-1999	1998	1998	1995	

* Unconfirmed

Visually a change in channel morphology is evident between each photographic epoch. One obvious observation is the realignment of the River between the Bowl Mill Bridge and the confluence with Alder Meadow Brook in the 1939 airphoto. Another observation pertains to the increase in length of channel subject to maintenance works in successive epochs. The third observation pertains to channel re-meandering. While the 1939 and 1974 airphotos were taken within a year of a major flood event and subsequent maintenance works, the 1962 and 1995 airphotos have lapse periods of 5 and 22 years respectively between either a major flood or maintenance event. The 1939 and 1974 airphotos show that the channel has been straightened, realigned and widened. The 1962 and 1995 airphotos show that the channel has a more sinuous form. These casual observations are reflected in the results of the airphoto analysis as summarized in Table 4.1 for Reaches 2 and 3.

Table 4.2 Summary of Channel Morphologic Parameters For Selected Reaches of the White River Through Granville

Epoch	Downstream of Mined Reach (Reach 3)					Within Mined Reach (Reach 2)				
	L_{THA} (ft)	W_{ACT} (ft)	A_{ACT} (ft^2)	ξ_{NMAX} (ft/yr)	ξ_{NAVE} (ft/yr)	L_{THA} (ft)	W_{ACT} (ft)	A_{ACT} (ft^2)	ξ_{NMAX} (ft/yr)	ξ_{NAVE} (ft/yr)
1939	3386	37	16,592	n/a	n/a	2228	40	27,127	n/a	n/a
1962	3191	55	25,075	2.0	0.9	2052	53	33,138	n/a	n/a
1974	3202	59	25,803	2.2	1.5	2047	39	24,575	n/a	n/a
1995	3259	66	30,096	1.9	1.0	2084	31	19,853	n/a	n/a

L_{THA} = Channel length along thalweg; W_{ACT} = channel width at top-of-bank of the active channel
A_{ACT} = active channel surface area; ξ_{NMAX} = maximum normal shift; ξ_{NAVE} = average normal shift

The same analysis was conducted for the West Branch of the Tweed River near Pittsfield (Table 4.3). These data were compared against the White River data to assess the degree of change in the White River. The difference in parameter values between epochs is reported in Table 4.4.

Table 4.3 Summary if the Morphometric Parameters for the Reference Channel: West Branch of the Tweed River Near Pittsfield

Year of Aerial Photo	West Branch of The Tweed River Near Pittsfield				
	L_{THA} (ft)	W_{ACT} (ft)	A_{ACT} (ft^2)	ξ_{NMAX} (ft/yr)	ξ_{NAVE} (ft/yr)
1939	2,532	38	29,504	n/a	n/a
1962	2,537	41	31,877	1.3	0.7
1974	2,527	38	28,958	1.3	0.7
1995	2,560	42	32,446	1.4	0.8

n/a = not applicable/not available

Table 4.4 Change in Channel Morphology for the Subject & Reference Reaches Relative to the 1939 Baseline Year

(Numbers in Brackets are Percent Difference (%DIFF)

Period		White River Town of Granville: Reach 2 (Zone of Mining;)				
From	To	L_{THA} (ft)	W_{ACT} (ft)	A_{ACT} (ft^2)	ξ_{NMAX} (ft/yr)	ξ_{NAVE} (ft/yr)
1939	1962	-176 (-7.9)	13 (32.5)	6,011 (22.2)	n/a	n/a
1962	1974	-181 (-8.1)	-1 (-2.5)	2,552 (-9.4)	n/a	n/a
1974	1995	-144 (-6.5)	-9 (-22.5)	-7,274 (-26.8)	n/a	n/a
		White River Town of Granville: Reach 3 (Downstream of the Zone of Mining)				
1939	1962	-195 (-5.8)	18 (48.6)	19,460 (51.1)	n/a	n/a
1962	1974	-184 (-5.4)	22 (59.5)	21,130 (55.5)	0.6 (66.7)	0.2 (10.0)
1974	1995	-127 (-3.8)	29 (78.4)	30,978 (81.4)	0.1 (11.1)	-0.3 (-15.0)
		West Branch of the Tweed River near Pittsfield (Reference Reach)				
1939	1962	5 (0.2)	3 (7.9)	2,373 (8.0)	n/a	n/a
1962	1974	-5 (-0.2)	0.1 (0.3)	-546 (-1.9)	0.001 (0.1)	0.01 (0.8)
1974	1995	28 (1.1)	4 (10.5)	2,942 (10.0)	0.1 (14.3)	0.1 (7.7)

The data in Table 4.4 indicates that the West Branch of the Tweed River has remained relatively constant (%DIFF<10%), over the study period in relation to the 1939 baseline year. The exception being an increase in the maximum normal shift (ξ_{NMAX}) of %DIFF=14.3% reported in the 1974-1995 Epoch and an increase in the width of the active channel (W_{ACT}) of %DIFF=10.5%. These data also indicate that the subject Reaches on the White River through Granville have relatively high geomorphic activity rates with the exception of thalweg length (L_{THA}).

Trends in channel form evident from these data are presented in Figures 4.4 to 4.8 and summarized below.

1. Reach 2 (the mined reach):
    a) channel thalweg length declined by 8% through the 1939-62 Epoch and showed negligible change in the later two Epochs. The ability of the channel two re-meander is constrained by armoring of the banks by boulders excavated from the bed;
    b) the width of the active channel increased by 32.5% in the 1939-62 Epoch but subsequently decreased by 26.4 and 7.1% for the 1962-74 and 1974-95 Epochs

Figures 4.4 and 4.5

Figures 4.6 and 4.7

Figure 4.8

respectively. The result is a net decrease in the width of the active channel of 25% relative to the 1939 condition and 31% when corrected for variations in the "reference" reach; and

c) the surface area of the channel exhibited the same trend as that described for active channel cross-sectional width.

Table 4.4 Change in Channel Morphology for the Subject Reach Normalized to the Reference Reach (1939 Baseline Year)

Period		**White River Town of Granville: Reach 2 (Zone of Mining)**				
From	**To**	L_{THA}	W_{ACT}	A_R **(ft^2)**	ξ_{NMAX} **(ft/yr)**	ξ_{NAVE} **(ft/yr)**
1939	1962	-40.0	4.1	2.8	n/a	n/a
1962	1974	41.1	-9.5	5.1	n/a	n/a
1974	1995	-5.8	-2.1	-2.7	n/a	n/a
		White River Town of Granville: Reach 3 (Downstream of the Zone of Mining)				
1939	1962	-29.2	6.2	6.4		
1962	1974	27.5	225.7	-30.0	466.7	13.0
1974	1995	-3.4	7.4	8.2	0.8	-21.0
		West Branch of the Tweed River near Pittsfield (Reference Reach)				
1939	1962	1.0	1.0	1.0	1.0	1.0
1962	1974	1.0	1.0	1.0	1.0	1.0
1974	1995	1.0	1.0	1.0	1.0	1.0

2. Reach 3 (downstream of the mined reach)
   a) channel thalweg length decreased by 5.8% during the 1939-62 Epoch and showed negligible change over the following two Epochs. The ability of the channel to re-meander is constrained by a chute located near the mid-point of the reach as well as geologic and bank protection works located in the lower portion of the reach;
   b) the width of the active channel has increased through all Epochs, however, the rate of increase in channel width has declined with each successive Epoch. When corrected for variations in the “reference” reach the increases in width for Reach 3 were 42%, 14% and 2% for the three respective Epochs. By the end of the 1974-95 Epoch the width of the active channel had enlarged by 78.5% of the 1939 value width;
   c) channel surface area demonstrated the same trend as described for active channel width. By the end of the 1974-95 channel surface area had increased by 81.5% of the 1939 value;
   d) the change in maximum normal shift is difficult to assess because values could only be determined for the later two Epochs. This excludes the first and apparently the most active Epoch (1939-62). Over the later two Epochs the maximum normal shift varied from an increase of 66.5% to a decrease of 47% respectively when corrected for variations in the “reference” reach. Through the study period maximum normal shift increased by 33.4% in comparison to an increase of 14% for the “reference” reach. Maximum normal shift is influenced by the same factors constraining re-meandering as noted in (a) above;
   e) average normal shift is also difficult to assess for the same reasons provide for (d)

above. Over the later two Epochs average normal shift increased by 9% and subsequently decreased by 29% when corrected for variations in the ”reference” reach for a net decrease in average normal shift. Average normal shift is also influenced by the same factors constraining re-meandering as noted in (a) above.

3. “Reference” Reach (Tweed River near Pittsfield)

   a) the thalweg length shows a marginal increase of 1.1% over the study period with variations ranging from -0.4 to 1.3%;
   b) active channel cross-section width oscillates about -7% and 10% through the study period with a net increase of approximately 11%;
   c) a similar trend to (b) above was observed for channel surface area with a net increase of 10%;
   d) as noted previously assessment of maximum normal shift is difficult because of the lack of data points. Over all the “reference” reach indicated that maximum normal shift had increased by approximately 14%;
   e) the trend noted in (d) above was also observed for average normal shift resulting in an increase of 7.7% over the period of 1962 to 1995.

These findings are summarized graphically in Table 4.5 and compared to common observations reported in case studies described in the literature review. The comparison shows that the “subject” reaches behave in a manner similar to that observed in the case studies. This finding implies that the case studies may be used to predict channel response to a disturbance created through gravel mining and flood hazard mitigation works.

Table 4.5 Summary of Aerial Photograph Assessment of the White River Through Granville (Reaches 2 and 3) and the West Branch of the Tweed River (“Reference” Reach) in Comparison to the Case Studies From the Literature Review

River & Reach	L_{THA}	W_{ACT}	A_R	ξ_{NMAX}	ξ_{NAVE}
White River: Reach 2	\	\	\		
White River: Reach 1	\	[[	[[	[	\

West Branch of the Tweed River		ΔL_{THA} . 0	[	[	[	[
Literature Review	**Mined Reach**	\	\	\		
	d/s of Mined Reach	\	[[	[[	[	\

SECTION 5.0
VALIDATION OF MORPHOLOGICAL RESPONSE MODEL

5.1 Application of Model to the Case Study

As noted previously, The Granville reach of the White River may be divided into three distinct segments. The first segment represents the reach upstream of the zone of gravel extraction (Reach 1). The second reach represents the zone of gravel extraction and flood hazard mitigation works (mined reach, Reach 2). The third reach is the channel segment downstream of the mined reach (Reach 3). Each reach was modeled as a separate entity, the initial conditions for each Reach were then updated based on the results for from the preceding iteration and the model was re-run. This process was repeated until a quasi-stable equilibrium channel form was attained.

The first reach is controlled by rock outcrops and consequently, is not susceptible to headcutting by nickpoints or other instabilities in channel gradient. The literature search indicates that the morphological impacts within geologically controlled channel segments located upstream of mined reaches are minimal. This was reflected in the model. Bed degradation was arrested by bedrock outcrops and channel widening was prevented from moving upstream by the Bowl Mill Bridge.

Within the mined reach the initial conditions were established from a 1998 survey (Appendix C) and a more detailed investigation of the channel conducted in May of 1999. The later survey was conducted approximately 9 months after completion of the maintenance works. Immediately downstream of the Bowl Mill Bridge the channel was confined and unstable. Adjacent buildings on the south bank and along Route 100 on the north bank were threatened by the potential for bank collapse and channel widening. Downstream of this confined section the channel following the 1998 flood and mitigation works had been enlarged to the point where channel may contain the maximum flood on record. Aggradation, was evident in the upper portions of this section and winnowing with associated slumping of coarse material was evident in the lower end upstream of the confluence with Alder Meadow Brook. This section is also the highest gradient segment within Reach 2. Channel works extended downstream a distance of approximately 1000 ft below the confluence.

Reach 3 had been bifurcated by a cutoff channel that had headcut during the June 1998 flood. The bifurcation is located 600 ft downstream of the end of Reach 2. A bar has formed along the mouth of the abandoned channel. Consequently, it only receives flows at near bankfull stage in the cutoff channel and drainage from a small tributary. Consequently, the abandoned channel is aggrading. The cutoff channel is still forming and appears to have a high degree of lateral instability although an incipient pool-riffle sequence is well defined with the exception of the lower portion of the cutoff channel that has been trifurcated by Large Woody Debris. Downstream of the point where the cutoff channel rejoins the original main channel, the thalweg is out of alignment with the previous morphology likely due to the change in flow patterns and flow energy caused by the angle of entrance of the cutoff channel. Large Woody Debris, changes in the sediment regime associated with formation of the cutoff channel and maintenance activities, and local armor all have a bearing on channel response.

5.2 Comparison of Model Prediction with Observed Morphological Response

The White River through Granville has been disturbed through periodic, intense but relatively short periods of instream activity. It has also experienced some less intense but longer duration periods of gravel extraction over limited areas. Prior to the recent (1998) flood and channel maintenance activities the last maintenance event was in 1974, some 24 years ago. The literature search indicated that channel impacts could be differentiated by the type of the gravel extraction activity and how recently it occurred. In those cases where gravel extraction had ceased sedimentation patterns dominated in both the mined and downstream reaches. In those channels where extraction was still active, erosional patterns dominated in both the mined and downstream reaches, if the sediment load to the downstream reach declined below stream competence and capacity. The White River situation appears to apply to the sedimentation patterns environment with some qualification. The gravel extraction and flood mitigation activities were intensive and applied to approximately 2000 ft of the channel. They also occurred relatively recently (within 9 months of the survey) and through a steep section of the channel (longitudinal gradient of 1 to over 2 percent). Finally, a spring snowmelt event had also occurred in the incised and destabilized channel prior to the survey. Consequently, an erosional environment is expected to dominate the initial response followed by a depositional environment. These response modes were well addressed by the proposed model.

Within Reach 2 the cutoff channel represents an increase in channel gradient and stream power. Consequently sediment transport potential has increased along with the influx of finer materials into the channel. Through bank collapse channel gradient is well within the meandering range, the banks are highly erodible and the high bed load impedes downcutting, consequently, bank erosion and lateral migration of the channel is anticipated. These observations were addressed in the proposed model.

The model required 10 iterations to converge on a possible quasi-stable channel form. The channel form within each iteration is illustrated in Figures 5.1(a) to (j) and summarized for Reach 1 in Table 5.1 below. Based on the findings in Table 5.1 the proposed model was able to reproduce the observed channel response well. The proposed model was then used to predict the ultimate quasi-stable channel form of the channel through the steep portion of the “subject” reach between the Bowl Mill Bridge and the confluence with Alder Meadow Brook. The final form of the channel was predicted to be a wider, shallower channel of lower gradient and higher sinuosity then the pre-disturbance channel from. This assumes that the River is given free reign to adjust its form toward a new equilibrium position and that no other instream or land use disturbances occur, during the adjustment period.

Figure 5.1 two pgs

Figure 5.1 two pgs

Table 5.1 Summary of Predicted Morphological Response to Instream Works in White River Through the Town of Granville Upstream of the Confluence with Alder Meadow Brook

Step	Observed Morphological Response	Predicted Morphological Response
a	Pre-1938 channel dimensions unknown and approximated from the 1939 airphoto and morphology of the West Branch of the Tweed River near Pittsfield	Assuming no maintenance activities precede the 1938, 1938 activities were relatively minor, then the pre 1937 channel can be approximated from the 1938 airphoto as the pre-disturbance channel form.
b	The 1998 maintenance activities resulted in the enlargement of the active channel through deepening and widening - channel in incised and bermed, banks armored - sediment structures destroyed - bed materials loosened - channel straightened and vegetation removed previously	The 1998 maintenance works provide the disturbance to the initial conditions required to begin the model
c	aggradation over majority of reach - winnowing of fines in lower section	loss of unit stream power for frequent floods - aggradation - tendency to concentrate flows - bar head formation
d	winnowing, slumping of coarse materials and development of an inset channel - active & floodplain channel depth increases - bank armor layer suspended - creation of discontinuity in bed - headward migration of grade discontinuity	winnowing, slumping of coarse materials, materials tend to become uniformly graded - inset channel forms - discontinuity in grade created - active & floodplain channel depth increases, ‘n” decreases, critical shear stress of bed material decreases - bank armor layer suspended - concentration of flows - increase in boundary shear stress - bed load export increases
e	end of 1999 observations	upstream propagation of grade discontinuity - inset channel widens through bank erosion - deepening through bed degradation - incipient active channel enlarges toward capacity of bankfull active channel - bankfull channel width decreases - remnants of previously aggraded material becomes incipient floodplain - colonization by riparian vegetation - flow capacity of incipient floodplain too low - ‘n’ value declines - grade declines
f		Incipient active channel over expands due to nickpoint migration or scour of bed (critical shear stress of bed material is less then instantaneous boundary shear stress for mid- to bankfull flows - grade decreases - ‘n’ value declines - sediment structures destroyed - bed material more susceptible to scour - degradation increases - channel deepens - renewed basal scour - channel begins to widen and degradation arrested
g		Active channel enlarges through basal scour - bankfull flow depth declines - unit stream power for bankfull declines - depositional environment created - channel begins to aggrade

Table 5.1 Contd.

Step	Observed Morphological Response	Predicted Morphological Response
h	Remeandering as observed from 1974 to 1995 photos	Aggradation and development of bar heads - decrease in active channel depth - decrease in active channel width - active channel capacity approaches bankfull flow - bars deflect flow against opposite bank - initiates process of meander formation and enhances bar formation - pool-riffle form development - sorting of bed materials - redistribution of bed materials - development of sediment structures
i	n/a	Lateral instability through meander development and propagation - large influx of bank sediments - bar formation accentuated - colonization and stabilization of bars resulting in incipient floodplain development - incipient floodplain flow capacity too low - increase in sinuosity - decrease in slope - fining of bed material - bed material sorting and redistribution - increase in active channel flow depth - decrease in active channel width - increase in ‘n’ value
j	n/a	Continued meander migration & floodplain development until capacity of incipient floodplain approaches riparian flood flow rate - channel now in quasi-equilibrium position with balance between sediment structures, hydraulic geometry, plan form geometry and sediment supply.

N/a = not available or not applicable

SECTION 6.0

FLOOD AND EROSION HAZARD MANAGEMENT

6.1 Introduction

There are many variables affecting a river's morphology. In short, to arrive at a solution, a watershed needs to be examined from a watershed perspective, examining land-use changes and other impacts on the watershed. Planning, zoning and stormwater and gravel extraction regulations must be combined with professional judgement and a good understanding of the dynamics of water and sediment within the watershed. Geomorphically designed flood control structures can protect existing infrastructure while maintaining the low-flow and bank-full channels in the watershed, ensuring they stay connected with the flood plain as flood flows occur.

6.2 Management Implications

Case studies reported herein note the significance of spatial scale. Streams within small watersheds are much more sensitive to the destabilizing effects of in-stream mining than large basins. The most extensive study to date of the impacts of in-stream mining recommends that small CDA<38.6 mi^2 (under 100 km^2,) basins not be mined. The least impact was associated with large CDA<386 mi^2 (over 1000 km^2,) basins with a braided morphology. Studies indicate that larger streams may be mined safely, provided that extensive cross-sectional surveys and hydrologic, meteorologic and sediment yield studies and professional judgement concur that gravel can be extracted according to a "safe yield" or "sustained yield" theory. However, despite the local stability at a "safe yield" site, a sediment deficit is created downstream of the site and channel instability may result due to the"hungry water" syndrome.

These findings and recommendations apply to Vermont rivers. Vermont has primarily straight, sinuous and meandering streams which are particularly sensitive to in-stream mining practices. These watersheds should not be considered as gravel sources. Split or braided rivers, primarily found near the mouth of large basins, are basins that could possibly be mined with a minimum disruption to channel stability, if best management practices and safe yield extraction techniques are followed. As noted previously, the location of the site of interest relative to mined reach (upstream, downstream or within the mined reach) also influences channel behavior.

In Vermont, gravel extraction has occurred historically on a number of small and medium sized rivers. Significant quantities have been extracted from the White, Mad, Trout, Brown, West Branch in Stowe, Huntington and the North Branch of the Deerfield. None has a naturally braided river formation. Vermont's rivers exhibit many of the same damages as those studied in the literature review. Fluvial processes are the same from state to state and from country to country.

There are many variables affecting a river's morphology. In short, to arrive at a solution, a watershed needs to be examined from a watershed perspective, examining land-use changes and other impacts on the watershed. Planning, zoning and stormwater and gravel extraction regulations must be combined with professional judgement and a good understanding of the dynamics of water and sediment within the watershed. Geomorphically designed flood control structures can protect existing infrastructure while maintaining the low-flow and bankfull channels in the watershed, ensuring they stay connected with the flood plain as flood flows occur.

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APPENDIX A

LITERATURE SEARCH

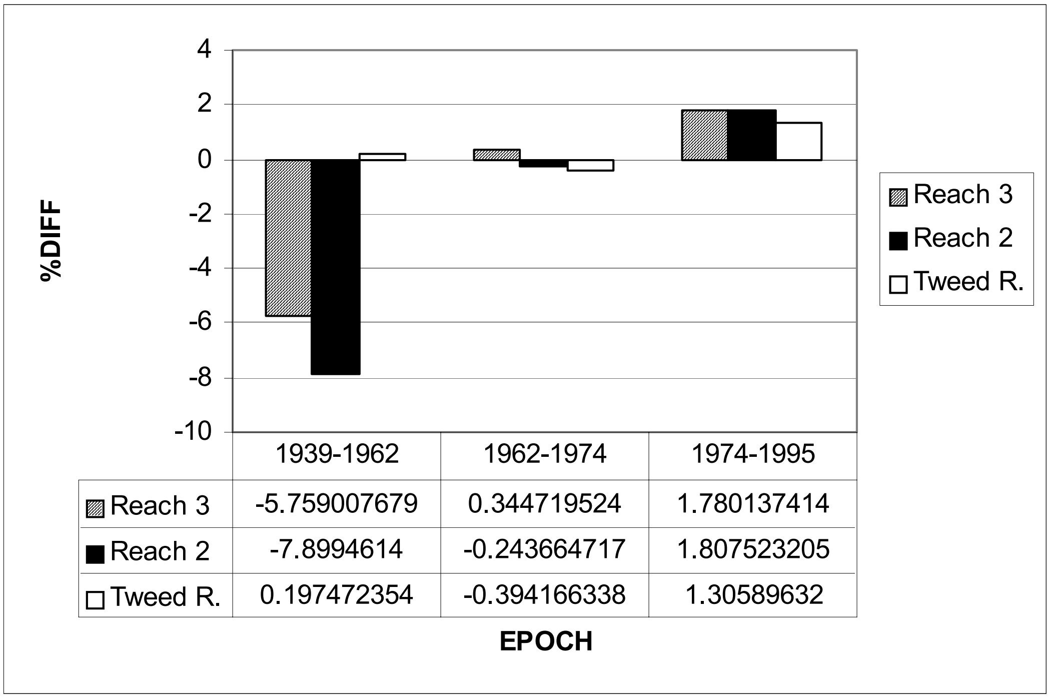
APPENDIX B

CONCEPTUAL MORPHOLOGICAL RESPONSE MODEL

APPENDIX C

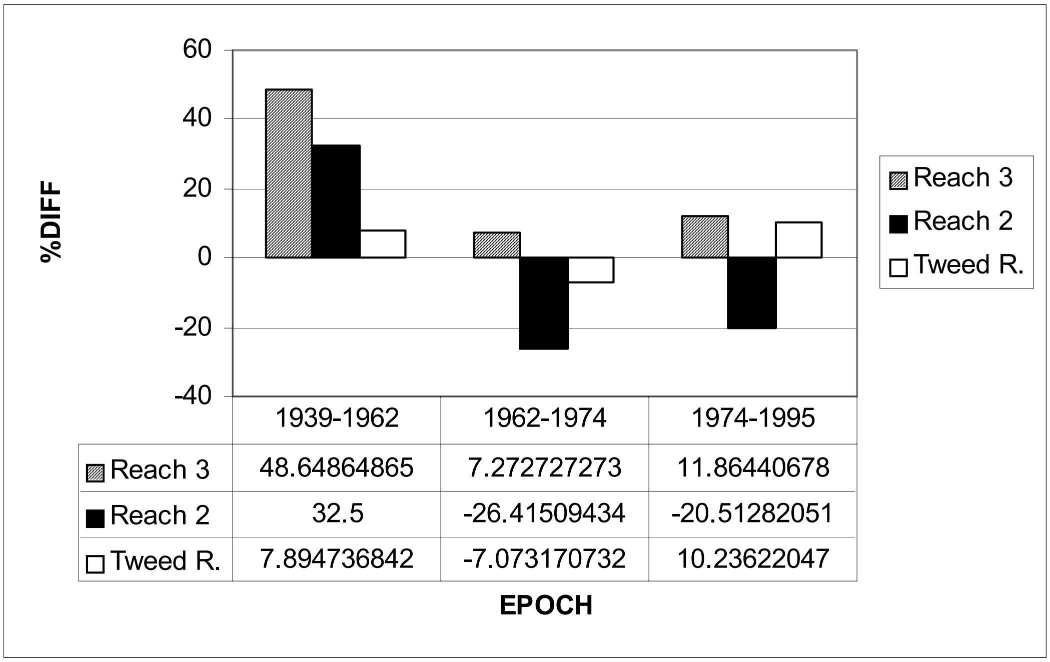
GRANVILLE-LINCOLN CHANNEL STABILITY ASSESSMENT

Figure 4.4 Trend in Thaleg Length



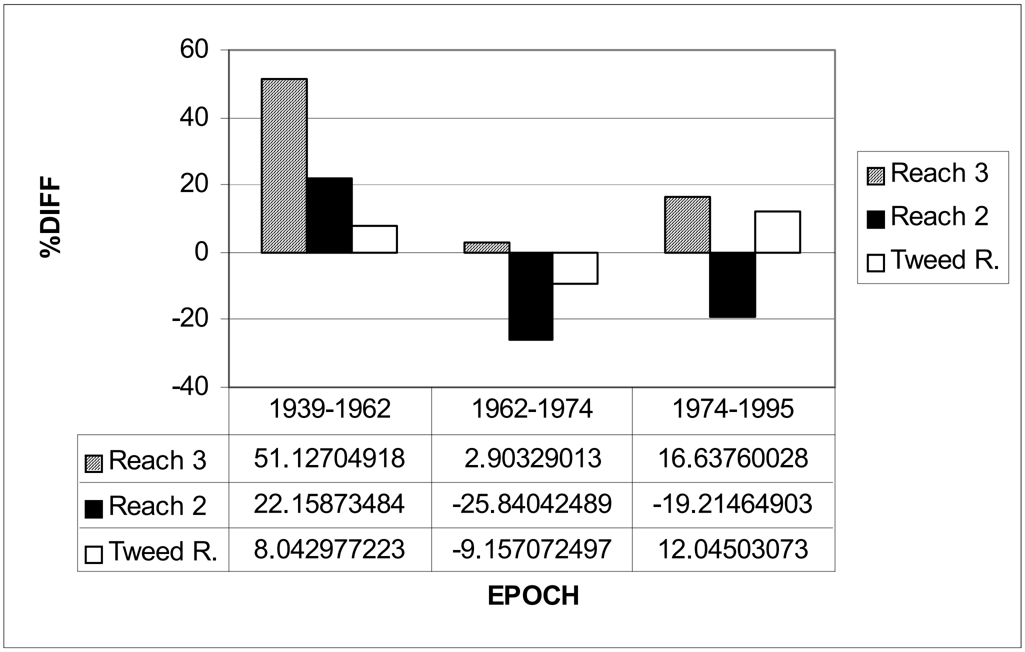
	1939-1962	1962-1974	1974-1995
▨ Reach 3	-5.759007679	0.344719524	1.780137414
■ Reach 2	-7.8994614	-0.243664717	1.807523205
□ Tweed R.	0.197472354	-0.394166338	1.30589632

Figure 4.5 Trend in Active Channel Cross-Section Width



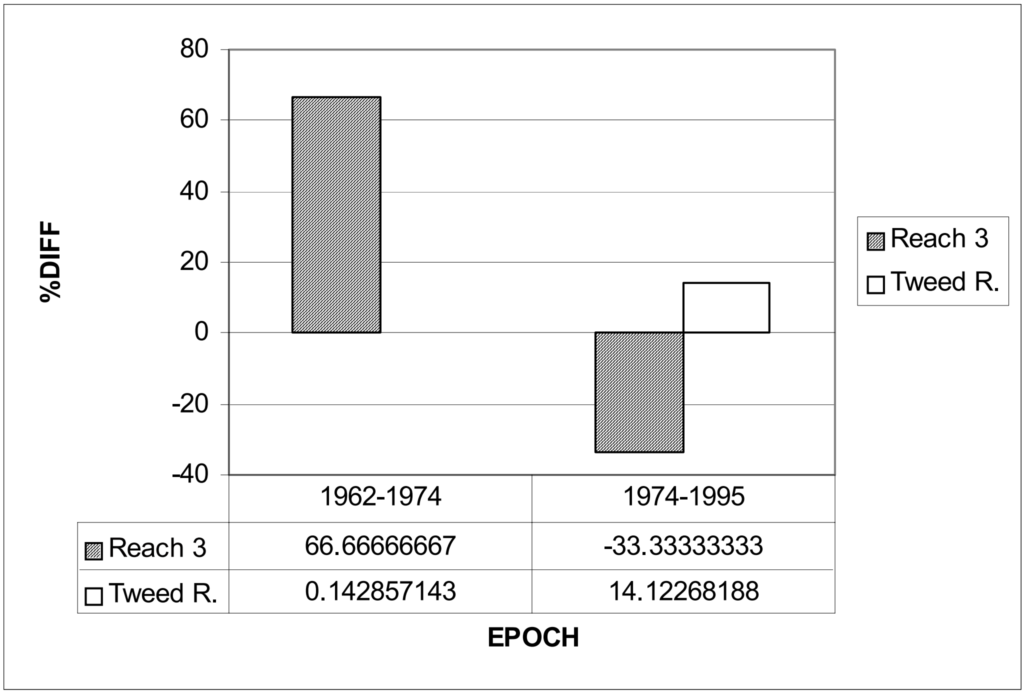
	1939-1962	1962-1974	1974-1995
▨ Reach 3	48.64864865	7.272727273	11.86440678
■ Reach 2	32.5	-26.41509434	-20.51282051
□ Tweed R.	7.894736842	-7.073170732	10.23622047

Figure 4.6 Trend in Channel Surface Area



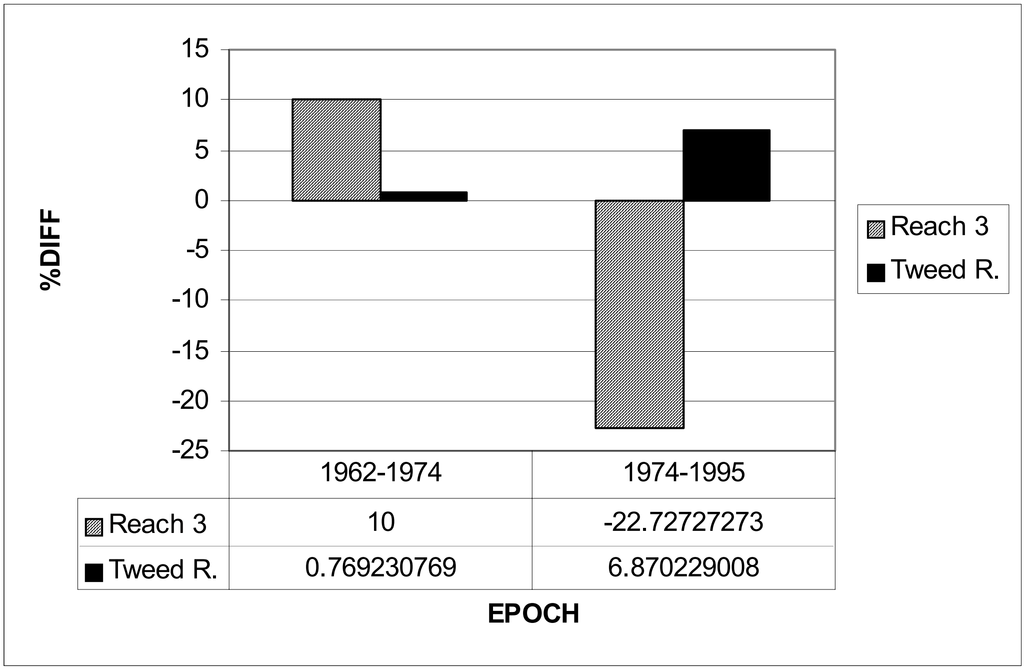
	1939-1962	1962-1974	1974-1995
▨ Reach 3	51.12704918	2.90329013	16.63760028
■ Reach 2	22.15873484	-25.84042489	-19.21464903
□ Tweed R.	8.042977223	-9.157072497	12.04503073

Figure 4.7 Trend in Maximum Normal Shift



	1962-1974	1974-1995
▨ Reach 3	66.66666667	-33.33333333
□ Tweed R.	0.142857143	14.12268188

Figure 4.8 Trend in Average Normal Shift



	1962-1974	1974-1995
▨ Reach 3	10	-22.72727273
■ Tweed R.	0.769230769	6.870229008

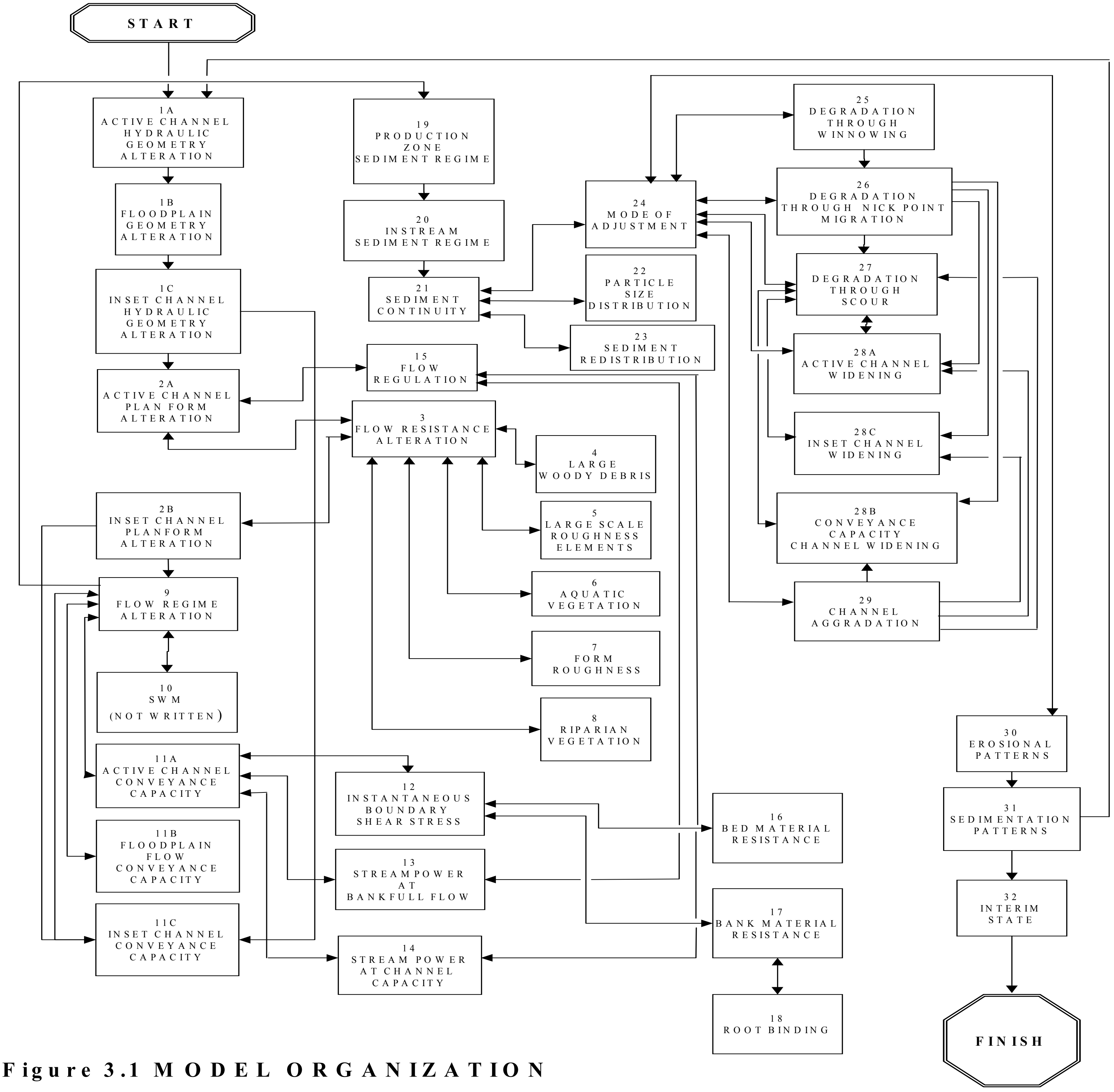


Figure 3.1 MODEL ORGANIZATION

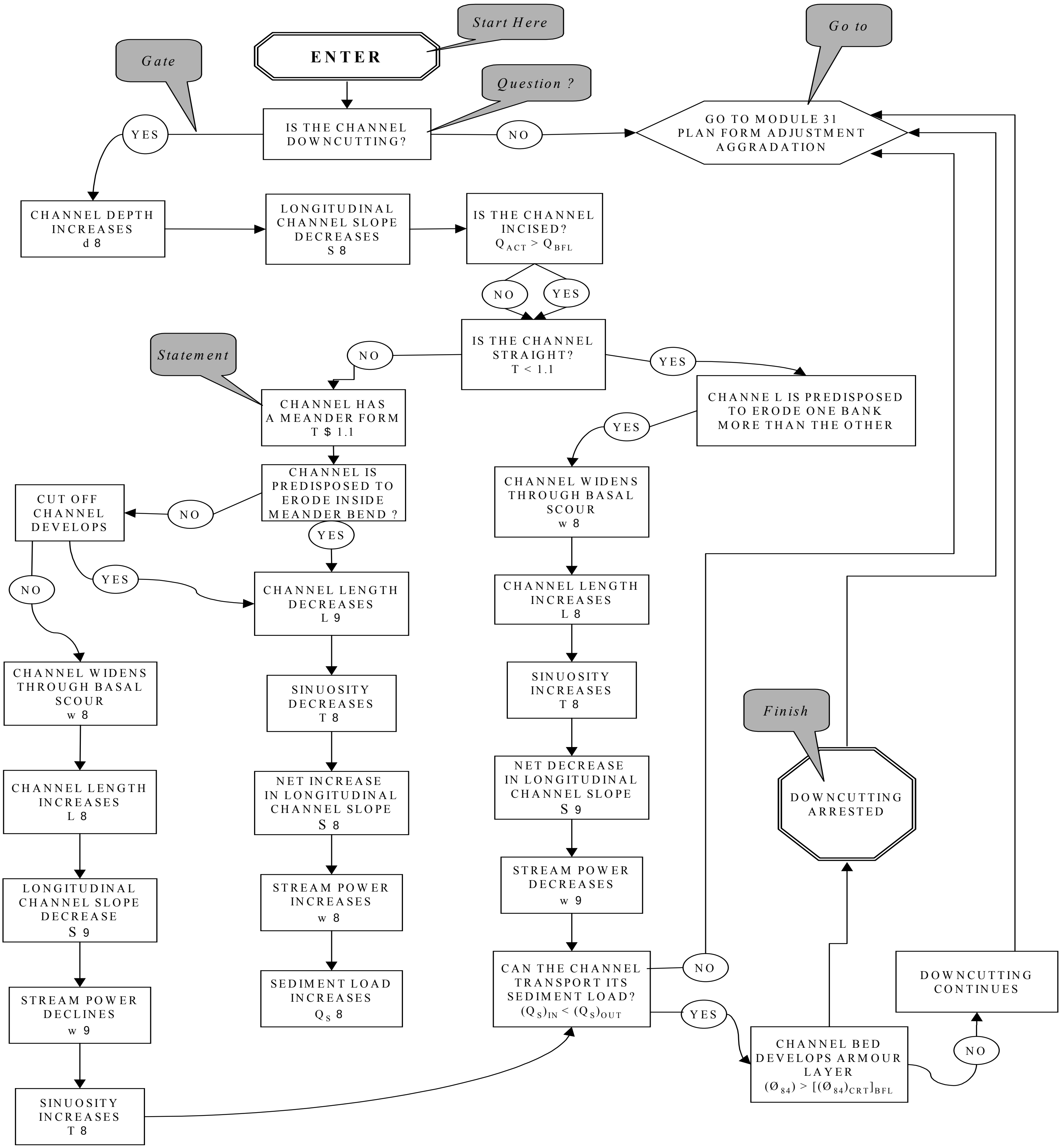


Figure 3.2 MODULE 30 EROSIONAL PATTERNS

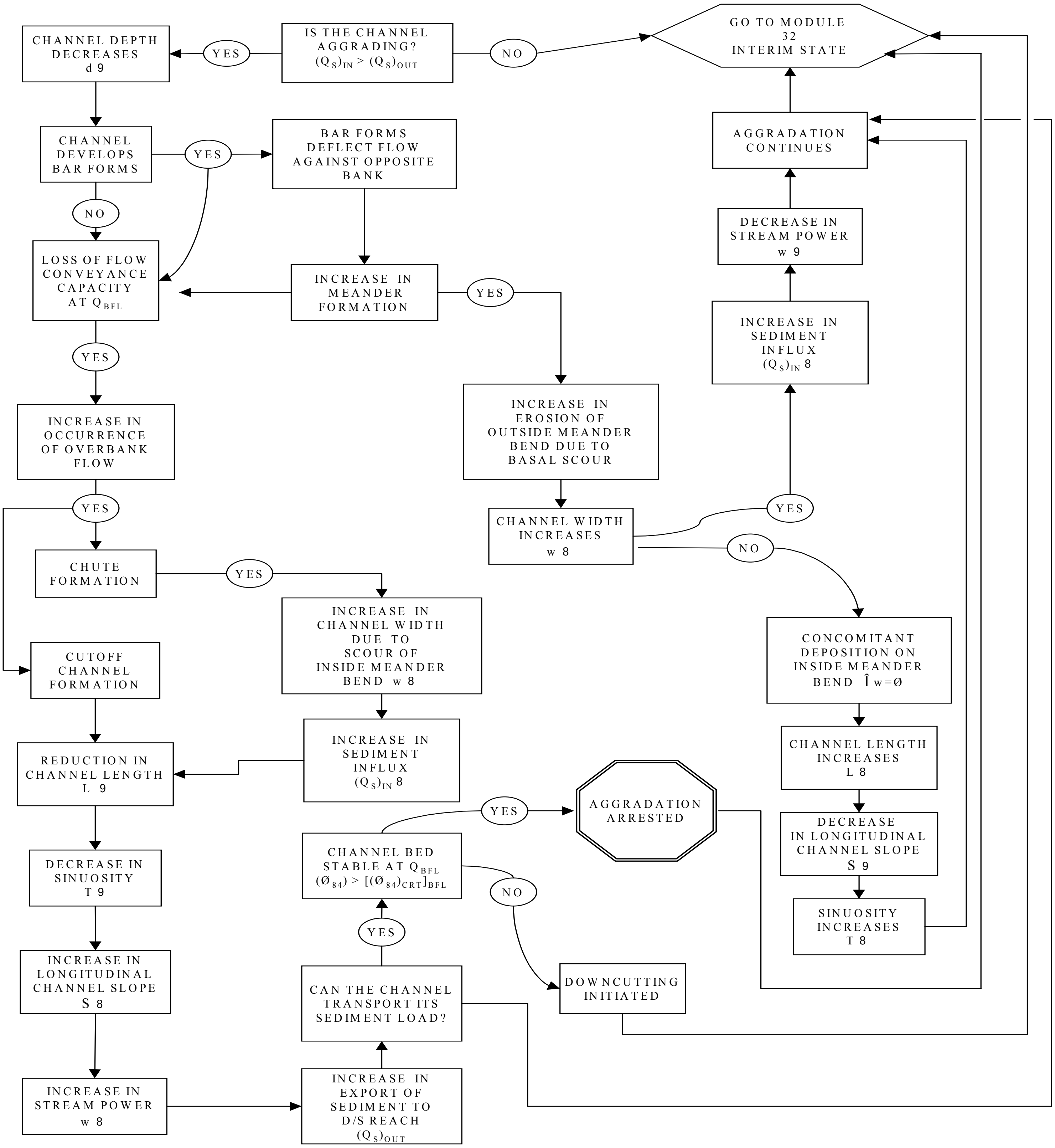


Figure 3.3 MODULE 31 SEDIMENTATION PATTERNS

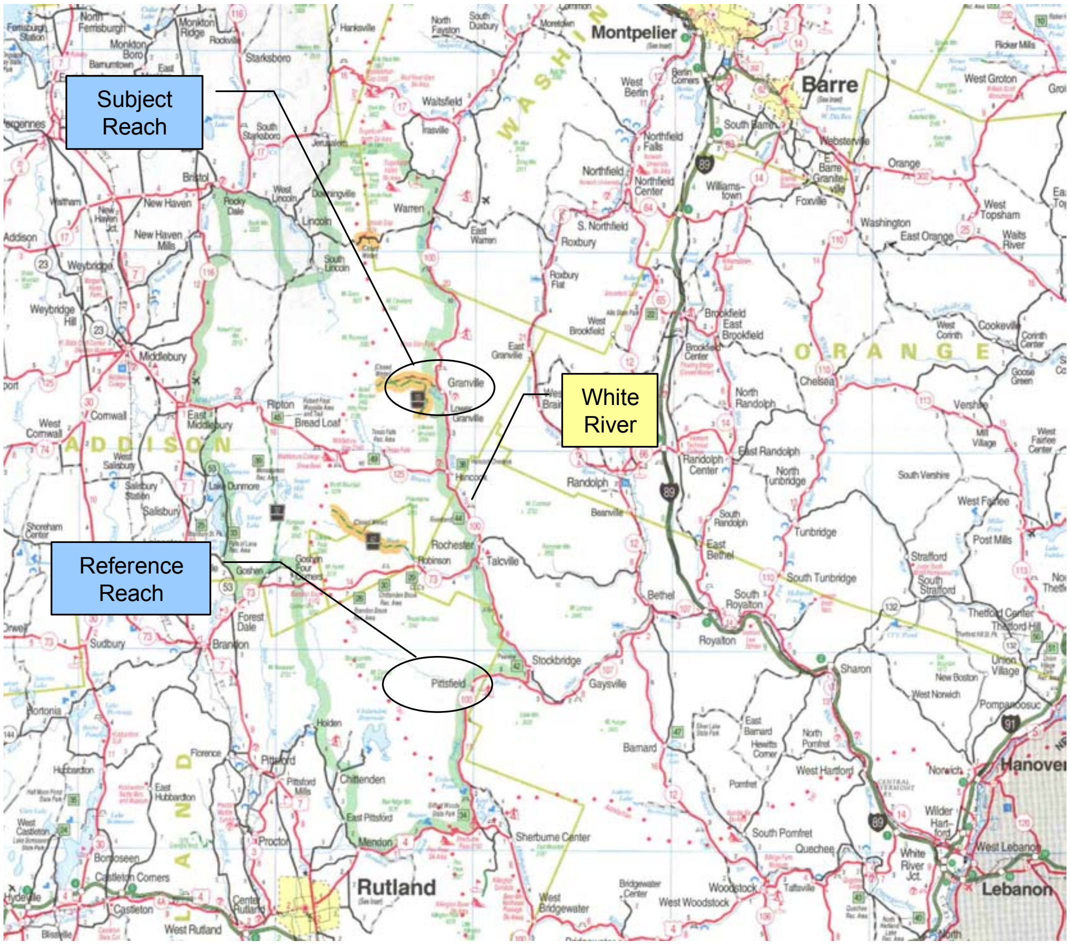

Subject Reach
White River
Reference Reach
Montpelier
Barre
Waitsfield
Warren
Granville
Lower Granville
Hancock
Rochester
Talcville
Pittsfield
Stockbridge
Gaysville
Bethel
Randolph
Middlebury
Brandon
Chittenden
Rutland
WASHINGTON
ORANGE
ADDISON
RUTLAND
Royalton
Sharon
Hanover
Lebanon
Woodstock
Bristol
Lincoln
Ripton
Goshen
Northfield
Chelsea
Tunbridge
Barnard
Sherburne Center
Mendon
Pittsford

Figure 4.1

APPENDIX A - SECTION 1.0

LITERATURE SEARCH

Tables A2 to A20

Table A2: Impacts of Gravel Mining on River Morphology

Name of River	Skykomish (46, 14, 7)	Naugatuck River (42)
Location	Gold Bar, Washington	Seymour Connecticut
Drainage area	535 and 1,780 sq. mi.	797 km^2
Channel Configuration	Braided	
Planform Changes	widening	Straightening of thalweg, widening
Topography	Steep, Cascade Mountains	Hillslopes
Geology		shallow soils and till over crystalline gneiss, Glacial outwash channel
Flows	Median peak flow, 1140 cms	
Peak runoff	Late fall, snow melt	
Land Use	Forested	Low rates of urbanization, densely wooded hillslopes
Channel Slope	.0015 m/m .0027 braided reach	
Thalweg Slope	.0038 headwaters .0011 below braided reach m/m	
Sediment Characteristics	Sediment Transport Capacity IndexI=1,291-3,753 21,000 y^3/yr	
Channel Constrictions		Dam 8 km upstream
Headcutting upstream		Prevented by upstream bedrock control
Upstream Impacts		Erosion of point bars
Downstream Impacts		Erosion of point bars or entirely removed
Bank Erosion	350 ft. during one flood 1990 (14)	Banks oversteepened due to mining, enlarged river cross-section
Channel Degradation (incision)		Average depth doubled
Channel Aggradation	2m max	
Changes in Width	1976=120m wide 1991=170m wide mannings n =0.041	Average bankfull widths increased by 30%, need 90,000 m^3 to return to pre-mining channel form
Channel stability	Decreased	decreased
Water Quality		Stagnant low O zones
Riparian Zone		Densely wooded

Alteration in flood flow conveyance	Could lower flood elev. by dredging 1-2 ft, but would raise flood elevations 1 ft immediately downstream of excavation, would need rip-rap at very high cost, dredging not recommended (2)	
Type of extraction		In-stream pit mining 1550 m of channel
Years since extraction	Began in 1961	1980 extraction ceased
Amount of extraction	1961 84,000 t/yr 1969 –1986 25,000 t/yr 76-79 17,000-25,000 t/yr	
Comments	Extraction competitive between neighboring bars, held as example of bank erosion reduced by bar scalping	

Table A3: Impacts of Gravel Mining on River Morphology

Name of River	Mad River (74)	White River (74)
Location	Waitsfield, Vermont	Granville, Vermont
Drainage area sq. mi	139 at Moretown	~18
Land Use	upland development, forested, agricultural	Forested slopes, agricultural valley
Channel Constrictions	Bridges	
Downstream Impacts		Excessive aggradation, downstream of channelized reach, extensive bank erosion
Bank Erosion	Riprap failing	Severe
Channel Degradation (incision)	3.5 ft, in 15 yrs	
Changes in Width	widened, incised	widened, incised
Channel stability	Decreased	Decreased
Alteration in flood flow conveyance		Channelized deeper and wider, banks built up higher, banks can't contain stress of flows, increased flooding downstream of channelized reach
Type of extraction	Scraping,	Scraping
Years since extraction	13	1-2
Amount of extraction	10,000 yds periodically, several locations 1 – 5,000 annually 1997-98 – 18,000 y^3/yr	1000s of yards at multiple locations annually till mid-80s G=1997- 98, Granville 6000 y^3/yr

Table A4: Impacts of Gravel Mining on River Morphology

Name of River	Trout River (74)	Browns River (74)
Location	Montgomery and Enosburg, VT	Underhill, Jericho, Vt
Drainage area sq. mi		92 in Fairfx
Channel Constrictions		Bridges
Downstream Impacts		Two private bridges undermined, one failed, one almost failed
Bank Erosion	highest rates of stream bank erosion in Vermont	Severe, landowners invested $10s of 1000s of dollars in rip-rap
Channel Degradation (incision)	yes	yes
Channel Aggradation		Downstream of mining
Channel stability	decreased	Decreased
Decrease Intergravel Flow		
Riparian Zone		All mature vegetation undermined and lost
Type of extraction	dredging	Mined heavily
Years since extraction	1997 dredging	mined in 1970s and 1980s
Amount of extraction	excavated “tremendous volumes”	1997-98 trib to Browns, 500 y^3/yr

Table A5: Impacts of Gravel Mining on River Morphology

Name of River	Puyallup, White and Carbon Rivers (70, 61)	Salmon Creek in Vancouver; Clackamas River in Oregon (54)
Location	Tacoma, Washington	Oregon, Vancouver
Drainage area sq. mi	1,000 mi^2	
Planform Changes		Thalweg straightening
Topography	Cascade Mountains and foothills, includes Mt Rainier	
Climate	Precip. annual-37 in, lower basin, 59 in. upper basin. Most rain from Oct – Feb.	
Flows	Mean annual flow 3460 cfs, White River 50% of flow, Carbon River 30% of flow	
Peak runoff	Most floods from storm events, flood control reservoirs	
Land Use	Flood plain developed, homes, agriculture, commercial building	
Channel Slope	.010 headwaters, .001 near mouth of Puyallup, .0005 near mouth of White	Grade steepening
Channel Constrictions	Levees or 'training structures" along most of study reaches	
Headcutting upstream		6 ft incision for 1/3 mi upstream on Clackamas, 4 ft incision, ¼ mi upstream on Salmon;
Channel Degradation (incision)	Degrading through most of the study area likely cause is gravel removal	Incision
Channel Aggradation	Aggradation of 1-3 y^3/yr per foot of river distance in limited reaches, 1.1-4.3 ft elev. change, sand aggradation more common than gravel	
Type of extraction	Scalping at many locations	Flood plain mining,
Years since extraction	During study	
Amount of extraction	1974-1985, 2,970,000 y^3 removed, deepened channel 1.3 ft along 42 mile stretch	pits of <5 acres, avulsion from larger pits too

Table A6: Impacts of Gravel Mining on River Morphology

Name of River	Middle Arve River (59)	Crooked Creek (43)
Location	Geneva, France	North central Arkansas
Drainage area	1985 km^2	462 mi^2
Channel Configuration	Braided for 8 km study reach, 300 – 500 m wide to 1950s, then incision began, changed to single narrow, straight channel	
Planform Changes	channel width reduced from 120 m to 50 m	
Topography	High relief	Gently rolling hills to steep precipitous bluffs, Ozark mountains
Geology	Glaciated mountains Mont-Blanc massif	Dolomite and Sandstone with large amounts of chert
Flows	Qm 79 cms, Q10 720 cms, Q100 1020 cms	
Peak runoff	Rapid runoff, high energy stream,	
Land Use		56% ag, 41% forest, 3% urban
Channel Slope	1912-.0028 1981.0018, slope reduced	
Sediment Characteristics	Bedload discharge 150,000 m^3/yr	
Channel Constrictions	Dykes caused aggradation in 19th cent., hydro electric dam since 1957	
Headcutting upstream		
Upstream Impacts		Bed loss, incision
Downstream Impacts		Gravel deposition
Grain Size Fining Downstream Armor Removal		Ref site <1mm =7% Disturbed site <1mm=37%
Bank Erosion		Yes, undercutting, sloughing
Channel Degradation (incision)	<10 m	Upstream, 1.3 – 1.6 ft incision in 2.5 years
Channel Aggradation		aggradation downstream of site, 30% loss due to scouring, ,
Changes in Width		W/D ratio: Disturbed sites: 88-160 Reference sites: 60 – 78 Upstream 55-80 Downstream 60-81 ratio of OHWM(bankfull)/DA=2 @

		disturbed sites, Ref. Sites =1
Channel stability		Decreased at disturbed sites
Water Quality		Temperature increase
Riparian Zone		Trees falling into channel
Type of extraction	Dredging began in 1950	Pit
Years since extraction		30 years ago
Amount of extraction	>500,000 m^3 by 1972	
Comments	Typical of rivers in France, lists similar impacts to Giffre, Fier and Rhone River	See tables 1-7 for details on channel geometry, excellent study

Table A7: Impacts of Gravel Mining on River Morphology

Name of River	Lower Mississippi River (39)	Amite, Tanipahoa, Bogue Chitto, Buttahatchee, Tombigbee (15a)
Location		Mississippi, Louisiana
Channel Configuration		Low gradient, deeply entrenched to shallow sand rivers
Planform Changes	2x more divided flow, multiple channel reaches as 20 years ago (Vicksburg), increase in discharge through chute channels at many locations	Loss of meander bends, stream capture of gravel pits
Topography		Flat
Geology		Limestone, shales
Climate		Hot, humid
Channel Slope		Low, slope increased as channels straightened, meanders lost
Sinuosity		Sinuous, but decreasing with channelization
Sediment Characteristics	D84 decreased from 1.5 mm to .67 mm, D50 decreased from .65 to .4, 1968 – 1974 through 200 mile reach of river, gravel decrease from 25% - 3%	
Channel Constrictions		Some berming, diking, bank stabilization
Headcutting upstream		Yes, all rivers have active headcuts up to 17,000 ft upstream of impact
Downstream Impacts	Easier to cut chute channels	
Grain Size Fining Downstream Armor Removal	Thin armor layer disturbed, coarser fraction depleted, shift in grain size from coarse sand in 1968 to fine sand in 1974	
Bank Erosion	Yes	Yes
Changes in Width		Widening, shallow, bank erosion
Channel stability	Decreased	Decreasing
Water Quality		Higher temp.
Fisheries Impact		Loss of many species of mussels
Alteration in flood flow conveyance		Flood elevations reduced when slopes increased
Type of extraction	Dredging,	Scalping, floodplain mines, pit mines
Amount of extraction	~522,000 metric tons a year	

Table A8: Impacts of Gravel Mining on River Morphology

Name of River	Illinois and King Rivers, Crooked Creek (4)	Salzach River (79)
Location	Northwest Arkansas	Salzburg, Austria
Drainage area sq. mi	Crooked, ~300 Illinois ~672 King~530	
Channel Configuration	Dendritic	
Planform Changes		Braided till 1820, then entrained to single channel av. width 152 m, 1873, reduced to 114 m, channel rapidly incised, bedrock control of sandstone
Topography	Ozark plateau	Central Alps 2,200 m source, steep, 345 m to 3798 m relief, 225 km. long
Geology	Limestone, chert intrusions, sandstone, shale	Igneous
Channel Slope	1m/km	
Sediment Characteristics		1966Bedload transport 320,000 m^3/yr d50=17 mm, 1976, bedload transport 122,600 m^3/yr, bedload coarser 1977 reduced to 76,000 m^3/yr
Grain Size Coarsening		Yes
Bank Erosion		
Channel Degradation (incision)		1965, 3.2 m incision, Hallein 5.2 m, Salzburg
Changes in cross-sectional geometry	**Disturbed/reference bankfull width** 39/26 m, Crooked 36/25 m, Illinois 54/39 m, Kings **Downstream/ref. bankfull width** 38/26m, Crooked 34/25m, Illinois 49/39m, Kings	
Pool/Riffle Change	Pools shorter than normal on Kings and Illinois Rivers, Longer on Crooked Creek, riffle pool sequence did not conform to ref. conditions	
Water Quality	High turbidity, sedimentation	
Riparian Zone	Reduced canopy in disturbed zones	
Type of extraction	10 gravel mines each on Crooked and Kings, 32 on Illinois	
Years since extraction		Still active

Amount of extraction		40-80,000 m^3/yr
Comments	See table 1 p 35	

Table A9: Impacts of Gravel Mining on River Morphology

Name of River	Dry Creek (17,7)	Russian River (12, 12a, 7)
Location	Healdsburg, California	Healdsburg, California
Drainage area sq. mi	562 km^2	3846 km^2
Channel Configuration		Historical river close in elevation to floodplain with low banks, now isolated from floodplain,
Planform Changes	Yes	Sinuosity decreased, incised, narrow and straight
Topography		3553'-4,500' relief
Geology	.9 m post-settlement alluvium	Deeply sheared and fractured, clay rich,
Climate		Mild, warm dry summers, cool wet winters, 80 in. precipitation in headwaters, 30 in. midbasin
Flows		Winter floods, summer low flows
Peak runoff		Mean annual runoff =20"
Land Use	50% forest 1850s 20% forest, grazing 1900	86% native vegetation, high parts forest, 4% irrigated, 3% urban, 7%dryland farms. Intense grazing of hills, lowland farming, urban Santa Rosa basin
Channel Slope	.00191 - .00194, no change over 44 years	.0005 in 1940 .0003 in 1991 downstream, .0009 upstream 1991, ~300 ft per mile in headwaters
Sinuosity		1.3 in 1864, 1.1 at present, meander amplitude decreased
Sediment Characteristics	D50=5.6 mm lower bank, .07 mm, upper bank	Suspended sediment 1000t/mi^2/yr, bedload transport 39,000 y^3/yr
Channel Constrictions	Dam upstream 1950s	
Headcutting upstream	Tributaries downcut	
Upstream Impacts	Bedrock exposed	
Downstream Impacts		Incision and channel widening
Grain Size Coarsening		Emerging bar heads, fine material winnowed from inactive areas
Bank Erosion	Yes	yes
Channel Degradation (incision)	3 m due to gravel extraction, new floodplain 1.4 m above bed. Each localized site of degradation, site of gravel extraction, 12 ft. incision at Westside Bridge between 1964-1978	6.1 m incision between 1940 – 1991, between 1982 – 1991 av. Bank height (thalweg/bank top) increased by 1.4 m, volumetric degradation of 10 million tons 1940 – 1972

Changes in Width	1940 9.8 m w, 3.6 m depth, 2.8 w/d 1984 101.8 m w, 5.8 m depth, 19 w/d	1982 – 1992 channel widening from ~190 - ~230 m Dominant discharge depth 60% of bankfull depth, river not in dynamic equilibrium
Pool/Riffle Change		Loss of deep pools
Channel stability	Rapid widening and downcutting	
Decrease Intergravel Flow	Water levels in wells dropped	
Riparian Zone		Loss of riparian zone, conversion to farmland
Alteration in flood flow		Isolated from flood plain
Type of extraction		Dredging, bar skimming, floodplain pits deeper than thalweg
Years since extraction	Began 1900, little effect till dams built in 1950	Still active
Amount of extraction		200-800,000 t/yr in 1970s, 57,000 tons =annual sediment load to Alexander Reach

Table A10: Impacts of Gravel Mining on River Morphology

Name of River	Giffre River (58)	Athi River Basin, Thwake, Kaiti and Muooni Rivers (65)
Location	Taninges, France	Kenya

Drainage area	325 km^2	38,000 km^2, no DA for study rivers
Channel Configuration	6th order stream, braided channel, 2.02 channels	Deeply incised, extensive sandy deposits
Planform Changes		
Topography	Intramountain plain in Northern French Alps, 616 – 725 m, steep slopes	600 m – 2150 m relief, steep slopes, intensive cultivation
Geology	Schistous limestones	Pre-cambrian gneiss, schist, magmatites, marine sediments
Climate		Arid, semi-arid, 500 – 1000 mm annual rainfall, mostly in october-nov, and less in march-may
Flows	Mean annual flow 19.3 cms	
Peak runoff	Snowmelt regime, summer and fall storms, flashy system	
Land Use	Slope clearing 18 and 19th cent. But good riparian protection	
Channel Slope	1912-1988=0.007, river changed to series of weir steps with reaches of low slopes	
Sinuosity	1.05	
Sediment Characteristics		sand
Channel Constrictions	Areas with dikes had less incision Seven bridges undermined	
Headcutting upstream	1.44 m incision	
Upstream Impacts		
Downstream Impacts	.9 m incision	
Channel Degradation (incision)	1 – 1.5 m incision 1973 – 1983	.43 m/yr mined reaches
Channel Aggradation	1988 – 1993 aggradation, after cessation of extraction, desired outcome	(unmined reaches +.21 m/yr)
Changes in Width	Width 86.2 m	Thwake, bankfull width 78m/65 m Mined/ref Kiati 48m /30m Muooni no change
Channel stability	7.5 km of bank destabilized	destabilized
Decrease Intergravel Flow	Drastic reduction groundwater resources	Diminished water supply
Riparian Zone	Being removed, was forested	

Alteration in flood flow conveyance	Slight decrease in peak flow during period of deep incision, remove gravel from aggrading areas due to development on flood plains	Bridge collapses during floods, sand harvesting bans 1-2 km upstream and downstream of bridges
Type of extraction	Instream	By hand, instream,
Years since extraction		Presently active
Amount of extraction	1973 – 1983 ~100-200,000 m^3 /yr, 6 of 13 km of study reach had gravel extracted	Exceeding supply, channel sand storage volumes 30-50% down, usual yield 1265 t km^2/yr, extraction beyond yield

Table A11: Impacts of Gravel Mining on River Morphology

Name of River	7 Small streams (19)	13 Medium streams (19)	5 Large Streams (19)
Location	Alaska	Alaska	Alaska
Drainage area	<100 km^2	100 – 1000 km^2	>1,000 km^2
Channel Configuration	Split, meandering, sinuous, straight Mean annual flow channel top width <15 m	Split, meandering, sinuous, mean annual flow top width 15 – 100 m	Braided
Planform Changes	Increased braiding, reduced average depth, reduced velocity, flow diverted through scraped area, more impact on small and medium rivers than large braided rivers	flow diverted through scraped area, low impact from gravel extraction on large braided rivers	Topography
Kigluaik Mountains or foothill, 1 glacial (Phelan Creek)	Kigluaik or Brook range Mountain or foothill	2 glacial, Brook range mountain, 1 coastal plain	Geology
Bedrock exposures common on upper slopes	Coastal delta, gently rolling terrain, underlain by permafrost	Climate	30-40 cm rain
		Flows	Mean annual flows m^3/s/km .0035 - .033, .063 Phelan River (glacial)
Mean annual flows m^3/s/km .0023- .033	Mean annual flows m^3/s/km .0045 - .012	Channel Slope	Moderate to steep
Mod. to steep, two mild		Sediment Characteristics	4 small and 4 medium streams with increase in bedload movement or suspended load
1 stream with increase in bedload movement or suspended load	Headcutting upstream	4 streams w/headcut	1stream w/headcut
2 streams headcut	Downstream Impacts	reduced average depth	
Grain Size Fining Downstream Armor Removal	5 streams with decreased armor coat or subsurface material size	4 streams with decreased armor coat or subsurface material size	
Bank Erosion	yes	yes	yes
Channel Degradation (incision)	upstream	upstream	upstream
Channel Aggradation	reduced average depth		Changes in Width

4 mountainous streams w/ channel width changes of <2 to >3 x Oregon Creek, wetted perimeter increased from ~5 to ~ 18 m above mine site and 30 m below mine site, Washington Creek increased below mine site	4 mountainous streams w/ channel width changes of <2 to >3 x	Sagavairktok River, wetted perimeter increased above and below mine site, and downstream Two large streams w/ channel width changes of <2 to >3 x	Channel stability
5 of 7 streams with increase in slope, "very substantial" decrease in lateral stability or channel degradation above mined area	8 of 13 streams with increase in slope, decrease in lateral stability, or channel degradation above mined area	1 of 5 streams with increase in slope, decrease in lateral stability or channel degradation above mined area	Decrease Intergravel Flow
		Yes	Type of extraction
Scraping, in channel , or in adjoining channel	Years since extraction	3-13	2-20
2-13	Amount of extraction	8,000-51,000 y^3/yr, Phelan Creek, 575,000 y^3 ratio volume/da 1.2/17, Phelan, 70	23,000 –630,000 y^3 ratio vol/DA <.8/<54
41,000 – 431,000 y^3 ratio vol. Ext/DA 0.1/1			
Comments	Mountain streams had more channel width response to gravel mining, see tables, study concluded small and med. Streams should avoid mining, as they experience greater impacts	Stream origins had no impact on response to gravel mining, see tables	

Table A12: Impacts of Gravel Mining on River Morphology

Name of River	Redwood Creek (8)	Amite River (27)
Location	Orick, California	Southeast, Louisiana
Drainage area sq. mi	278 sq mi	2,000 km^2
Channel Configuration	Sinuous plan form	Meandering in undisturbed reaches
Planform Changes	Thalweg shifted, bed is flattened, poorly defined incised channel, gravel bars degraded 2 ft, beds flattened	Braided where mining has occurred
Topography		
Geology	Weak sandstones, mudstones and schists	Unconsolidated clastic sediments
Climate	Seasonally high rainfall	1500 mm/yr precip, floods by storms, tropical systems
Flows		
Peak runoff		
Land Use	Extensive timber harvest increased sediment yield, began in mid 1950s, 81% old growth logged by 1978	
Channel Slope		
Thalweg Slope		
Sinuosity		Decreased through meander cut-offs
Sediment Characteristics	Bedload discharge 191,000 t/yr 1954 – 1980	
Channel Constrictions	Downstream of Redwood park channelized in 1968	
Headcutting upstream	degradation	
Upstream Impacts		
Downstream Impacts		
Grain Size Fining Downstream Armor Removal		Loss of armor, downcutting initiated
Grain Size Coarsening		
Bank Erosion		
Channel Degradation (incision)	Degradation at excavated site	
Channel Aggradation	Aggradation due to logging 1964	
Changes in Width		Increased width/depth ratio

Pool/Riffle Change		
Channel stability	Destabilized, bars built on opposite banks from original location	Decreased in areas with mining, timing coincides with sand and gravel extraction
Decrease Intergravel Flow		Water table changes
Water Quality		
Riparian Zone		
Fisheries Impact		
Alteration in flood flow conveyance		
Type of extraction	Scraped	Large floodplain pits, some in-channel and point bar mining
Years since extraction	1987 began extraction	
Amount of extraction	Extraction limit to annual bedload , 1987-107,000 m^3, 1988-87,000	<10,000,000 tons/yr (sand and gravel)

Table A13: Impacts of Gravel Mining on River Morphology

Name of River	Humptulips and Wynoochee Rivers (7)	Lower Manawatu River (7)
Location	Montesano, Oregon	North Island, New Zealand
Drainage area sq. mi		2300 mi^2
Channel Configuration		Low sinuosity channel, coarse-grained gravels upstream, downstream, highly sinuous channel in fine sand and silt (former estuary)
Topography	Southern Olympic Mtns.	Downstream, low gradient deltaic plain
Geology	Basalt, sandstones, siltstones thick deposits of gravel and sand from last glaciation	
Climate	3,300 – 3,800 mm annual precip	
Channel Slope	Humptulips .0023 to .0004 (headwaters to lower basin) Wnyoochee, .0017 to .000 Satsop, .0015	
Sediment Characteristics	D84=~25-40 mm D50 = ~8-18 mm	
Channel Constrictions	Extensive Army Cof E projects Dam upstream had no effect since it was above main sediment source, degradation due to gravel mining	
Channel Degradation (incision)	Degradation, due to over-extraction rates 500,000 y^3 between riv.mi 2 and rm 11 0n Wynoochee, Humptuilips, 800,000 y^3 degradation ~2 ft incision from 1940 – 1980 on both rivers	23 mile mined reach with calculated 1.2 – 1.4 ft of degradation over 20 years and measured 0.9 ft over 10 years 1964 – 1977 3.3 ft incision 1972 – 1977 1.5 ft
Channel Aggradation		
Changes in Width	No change in width (aerial photos over 44 yr)	
Type of extraction		
Years since extraction		Extraction since 1900
Amount of extraction	530,000 y^3 on Wynoochee Humptulips= 1,000,000 y^3 Extraction exceeded supply by factor of 10	250,000 y^3/yr, exceeding replenishment rate of 100 – 130,000 y^3/yr

Table A14: Impacts of Gravel Mining on River Morphology

Name of River	Cache Creek (7)	Lower Mackenzie River (80)

Location	Yolo, California	Coburg, Oregon
Drainage area sq. mi	1150 mi^2	
Channel Configuration	Upstream portion steep slopes through canyon to narrow alluvial valley at Capay Downstream intense braiding and channel shifting	
Geology	Alluvium 50 – 300 ft thick, highly erodible	
Land Use	Irrigation diversions,	
Channel Slope	.0027 around 1/3 of the way upstream .00095 near mouth	
Sediment Characteristics	D50=3.2 mm, bedload transport 77,000 t/yr in lower reach	
Channel Constrictions	All bridges undermined	Wooden irrigation diversion sill decaying
Headcutting upstream	Nickpoint extended 700 m upstream 3 m deep	
Upstream Impacts		Degradation
Downstream Impacts		Degradation
Channel Degradation (incision)	1959 – 1980 15 ft pre-1947 lowered .04 ft year, 1947 – 1967, 0.27 ft/yr degradation corresponds to extraction, confirmed with aerial photos, net lowering of 8 m	Severe incision 6 ft in 26 years
Channel Aggradation		
Changes in Width	Net narrowing of channel, new land will not have floodplain soil properties	
Decrease Intergravel Flow	Groundwater levels dropped	
Alteration in flood flow conveyance	Flood capacity increased by 50 – 100,000 cfs, max flood on record is 41,400 cfs	
Years since extraction	Since 1930s between Yolo and Capay	
Amount of extraction	Pre-1950 300,000 t/yr 1951-1957=900,000 t/yr 1957-1970, 2,000,000 t/yr 1976 – 1986, 2,600,000 t/yr total 80 –90 million tons from 14.5 mi reach	

Table A15: Impacts of Gravel Mining on River Morphology

Name of River	Tujunga Wash (67, 80, 5)	Stony Creek (25)
Location	California	California
Drainage area sq. mi	115 mi^2	1,920 km^2
Channel Configuration	Low flow bar -braided pattern , high flow complexly braided w/multiple bars, flows over upslope part of alluvial fan	Reach 1=braided, 0.0024 slope Reach 2=braided, narrower and more stable .0018 gradient Reach 3 (.0021 slope) wider, braided, large medial gravel bars Reach 4, sinuous, stable
Planform Changes		Reach 2, braided to single thread 1950 – 1990 Reach 3, active channel narrowed, low flow channels obliterated by gravel mining, active channel narrowed w' incision Reach 4, narrowing of active channel
Topography	San Gabriel, San Bernardino Mountains, erosion-resistant, steep dissected slopes, basin relief 1290 ft - 7124 ft	Basalt hills, steep headwater bedrock canyons onto low gradient valley floor
Geology	Semi-arid, fanhead valley	
Climate		Mediterranean, mild winters, 90% of annual precip from Nov-April, 1500 mm precip in headwaters to 450 mm on alluvial fan
Flows	Ephemeral Channels, 106 sq. mi DA, 50 year return flow = 20,000 cfs	
Land Use	Urbanization increased peak frunoff	
Channel Slope	Av. Slope=135 ft/mile over 25 miles	
Sinuosity	<1.3 in low-flow channels	D50 =16mm in lower Stony Creek, decreasing to 1 mm !1 km upstream from Sacramento River
Sediment Characteristics	Sediment load to Big Tujunga 2,500 y^3/mi^2/yr, mean size =40-100 mm	
Channel Constrictions	Flood Control "Big Tujunga"Dam for 71% of basin Three highway bridges fiailed w/knickpoint migration	One highway bridge repaired 3 x, cost $2 million, Black Butte dam closed in 1963, stream regained sediment load through incision and lateral migration to get 20,000 m^3/an (20% of pre-dam sediment load)
Headcutting upstream	Scour migrated 3000 ft upstream from nickpoint	
Bank Erosion	Lateral scour destroyed one street and 7 homes, 75 ft from urbanized left bank, 125 ft from right bank, thalweg scour of 11 ft	Reach 1, incision and lateral migration , 90 ha bank erosion, banks contributed average bedload of 20,000 m^3 since 1973

Channel Degradation (incision)	Net scour of 14 ft in formerly active channel, gravel pit filled with sediment	Reach 3, Highway 32 bridge channel degraded 5m between 1974 – 1990 Reach 4 downstream of gravel mines incised 2 m from 1967 – 1990, by Highway 45 bridge, 1m of incision from 1974 - 1978
Channel Aggradation	12 m in formerly inactive channel	
Changes in Width		lateral migration, 90 ha bank erosion
Pool/Riffle Change	Pools and riffles not well defined	
Channel stability	decreased	decreased
Type of extraction	pit	
Amount of extraction		230,000 – 580,000 m^3/yr , mostly in 5 km reach near highway 32 bridge

Table A16: Impacts of Gravel Mining on River Morphology

Name of River	Wooler, Water River (68)	Little Bighorn River (3)
Location	Northumberland, England	Southeast Montana
Drainage area	52.5 km^2	620 km^2
Channel Configuration	Laterally active, wandering	Sinuosity increases downstream
Planform Changes	Incised gently sinuous, getting more entrenched	
Topography		Bighorn Mountains, 1240 – 3020 m
Geology	Granite, andesite sandstone, thick glacial sands, gravels,clay	
Flows		Av. ann peak 32.6 cms, w/ 500 ^{km2} DA
Peak runoff		Snowmelt
Land Use	Moorland, pasture, gravel extraction	Alpine zone, conifers (high), shrub and grassland, grazing (low)
Channel Slope	.06 stream length 26 km	<1% lower basin >3 % upper basin gradient increased up to 25%
Sinuosity		1939=1.78 1987=1.36
Sediment Characteristics	D16=80 mm, D50=152 mm D84=215 mm Sediment Yield 145 m^3/yr	Floodplain silt and sand 25-30 cm (?), 60-75 cm. (I think they mean mm)
Channel Constrictions		Aggradation trend may be due to downstream bridges or riprapping and channelization of 53% of 193 km mainstem
Headcutting upstream	Yes, 1km. Minimum	
Downstream Impacts		Aggradation, loss of sinuosity, active channel widening
Bank Erosion		15,000 m^3 soil permanently eroded, 45,000 m^3 locally eroded
Channel Degradation (incision)	1966-1995, 9 m max	1989, 0.4 – 1m, river disconnected from historical flood plain
Channel Aggradation		Reference reach, thalweg =0.57m. Disturbed reach, thalweg = 0.44 m
Changes in Width	1948= 3x wider 1958 2x wider 1973=narrower	U/stream ref. 13.1 m Disturbed 42.4 m D/stream= 24.1 m
Channel stability	Decreased	Decreased

Riparian Zone	Trees lost, fields full of boulders	No canopy in disturbed area, loss of riparian zone, major disturbance to riparian zone during study period
Alteration in flood flow conveyance		During flood of record, no major shift in average bed elevation, Bankfull in reference reach 1.25-2.5 yr. return, in disturbed reach 20 yr return for bankfull
Type of extraction	2.5 km reach, 32,000 m^3/yr	15,000 m^3 rearranged, 3.6 ha of channel disturbed
Years since extraction	20	Jan-Mar 87, berm construction, spring 87, major channel changes with relatively low flow
Type of study	Aerial, maps	Aerial
Comments		See table 11.2 p 249

Table A17: Impacts of Gravel Mining on River Morphology

Name of River	Mad River

Location	Humboldt County, California
Drainage area sq. mi	485
Channel Configuration	Alluvial
Planform Changes	Meander tightening and downstream migration
Topography	Alluvial valley
Geology	Franciscan Assemblage: sheared sedimentary and metamorphic rocks, active tectonic uplift and subsidence
Climate	Mediteranean-type: seasonally high rainfall (winter months)
Flows	Highly variable year-to-year and within year (orders of magnitude)
Peak runoff	81,000 cfs (Dec, 1964)
Land Use	Timber harvest in steeplands; agriculture and minor urbanization in valleys
Channel Slope	0.0016 to 0.0028
Thalweg Slope	same
Sinuosity	1.03 to 1.23
Sediment Characteristics	Gravel, sand, cobble D50 3-6 mm
Channel Constrictions	Natural gorge reach, bridges, levee segments
Headcutting upstream	yes
Upstream Impacts	None above mined reach (no infrastructure there) Bridges and municipal water intakes undermined within mined reach (upstream of several mine operations)
Downstream Impacts	Channel incision, bridge undermining, mouth migration threatened coastal highway
Grain Size Fining Downstream Armor Removal	Probably both
Grain Size Coarsening	None likely
Bank Erosion	472 acres from 1962 – 1992, 16 acres/yr 1993 – 97, 8 acres/yr loss, 2-3 acres in 1998

Channel Degradation (incision)	Yes
Channel Aggradation	None likely
Changes in Width	Widened, deepened
Pool/Riffle Change	Fewer riffles
Channel stability	Naturally unstable, may be enhanced by mining
Decrease Intergravel Flow	Unknown
Water Quality	High turbidity related to natural basin erodibility, may be enhanced by timber harvest, but not mining
Riparian Zone	Loss of riparian trees from agriculture, channel widening
Fisheries Impact	Loss of bar confinement of low flow channel, LWD
Alteration in flood flow conveyance	* Randy Klein
Type of extraction	Skimming, historic dredging
Years since extraction	Still active
Amount of extraction	1962-91 high volumes extraction 420,000 – 800,000 y^3/yr. 1992-98 ave 180,000 y^3/yr

*Flooding Myths

Most of the Mad River info above is from the "Technical Appendix to the PEIR on Gravel Mining in the Lower Mad River" (1994). All information in Tables 17 and 18 is from Randy Klein, consulting hydrologist, 1999.

Table A18: Impacts of Gravel Mining on River Morphology

Name of River	Lower Van Duzen River	Lower Eel River
Location	Humboldt County, California	Humboldt County, California
Drainage area sq. mi	426	3,113
Channel Configuration	Alluvial	Alluvial
Planform Changes	Meander migration	Meander migration
Topography	Alluvial valley	Alluvial valley
Geology	Franciscan Assemblage: sheared sedimentary and metamorphic rocks, active tectonic uplift and subsidence	Franciscan Assemblage: sheared sedimentary and metamorphic rocks, active tectonic uplift and subsidence
Climate	Mediteranean-type: seasonally high rainfall (winter months)	Mediteranean-type: seasonally high rainfall (winter months)
Flows	Highly variable year-to-year and within year (orders of magnitude)	Highly variable year-to-year and within year (orders of magnitude)
Peak runoff	48,700 cfs (Dec, 1964) (gaged some miles upstream where area is 222 sq. mi.)	752,000 cfs (Dec, 1964)
Land Use	Timber harvest in steeplands; agriculture and minor urbanization in valleys	Timber harvest in steeplands; agriculture and minor urbanization in valleys
Channel Slope	0.0024	0.0008 (approx)
Thalweg Slope	same	same
Sinuosity	1.16	1.14
Sediment Characteristics	Gravel, sand, cobble	Gravel, sand, cobble
Channel Constrictions	Bridges, levee segments	Bridges, levee segments
Headcutting upstream	unknown	unknown
Upstream Impacts	Constrictions causing meander tightening and bank erosion; no known upstream impacts from mining	No known upstream impacts from mining
Downstream Impacts	Unknown	Unknown
Grain Size Fining Downstream Armor Removal	Probably both	Probably both
Grain Size Coarsening	None likely	None likely
Bank Erosion	Some, but not quantified	Some, but not quantified

Channel Degradation (incision)	Likely	Likely
Channel Aggradation	Maybe some from upstream timber harvest	Maybe some from upstream timber harvest
Changes in Width	Widened, deepened	Widened, deepened
Pool/Riffle Change	Unknown	Unknown
Channel stability	Unknown	Unknown
Decrease Intergravel Flow	Unknown	Unknown
Water Quality	High turbidity related to natural basin erodibility, may be enhanced by timber harvest, but not mining	High turbidity related to natural basin erodibility, may be enhanced by timber harvest, but not mining
Riparian Zone	Loss of riparian trees from agriculture, channel widening	Loss of riparian trees from agriculture, channel widening
Fisheries Impact	Loss of bar confinement of low flow channel, LWD	Loss of bar confinement of low flow channel, LWD
Alteration in flood flow conveyance	Unknown	Unknown
Type of extraction	Skimming, historic dredging	Skimming, historic dredging
Name of River	Lower Van Duzen River	Lower Eel River
Years since extraction	Still active	Still active
Amount of extraction	Approx. 150,000 y^3/yr	Approx. 650,000 y^3/yr
Type of study	EIR w/o much technical or quantitative analysis	EIR w/o much technical or quantitative analysis
Comments	Needs quantitative historical geomorphic analysis for estimating sustained yield	Needs quantitative historical geomorphic analysis for estimating sustained yield

information from Randy Klein

Table A19: List of Specific Impacts to Rivers (mentioned in review-type studies)

River	Location	Upstream Impact	Downstream Impact	Incision	Structural Damage or Failure	Planform Change
San Juan Creek (26)	California	bed widening				
Thomes, Santa Clara, San Diego, San Luis Rey San Benito Mad Rivers (32)	California			x	bridge, aqueducts, gas pipeline, irrigation on all	
Kaoping Bridge(32)	Taiwan	headcutting			bridge	
Blackwood Creek (32)	California	headcutting	aggradation, instability			
Clackamas River (32)	Oregon	2m for 1 km			building undermined	
Merced River (32)	California					x
Tolumne River (32)	California					x
Santa Clara River (27)	California			x	bridge failed	
San Diego River (27)	California			x	bridge failed	
Clear Creek (27)	California	incision		x		
San Simeon Creek (27)	California	incision, bed coarsening				
Blackwood Creek (27)	California	incision, erosion	incision, erosion	x		straightened to allow gravel mining
Yuba River (27)	California	incision		x	gravel mining only partly responsible for bridge failure	
River Usk (27)	Wales	aggradation in overwidened channel				

Table 20: List

of Specific Impacts to Rivers (mentioned in review-type studies)						
Otaki River (27)	New Zealand			x	undermined flood control works	
Waimakariri (27)	New Zealand	bank erosion, degradation	aggradation			gravel mining to prevent planform change
150 rivers (80)	California				bridge failure	
San Diego Santa Clara Kaweah Rivers (24)	California			x x x	bridge failure	
Kelsey Putah San Juan Temecula Creeks (24)	Califoronia			x x x x	bridge failure	
Broad R.(53a)	Tennessee		aggradation			
Cumberland R (53a)	Tennessee		aggradation			
Brazos R (53a)	Texas		aggradation			
Linn Creek (63)	Missouri				bridge failure	
Roubidoux R (63)	Missouri			x	utilities exposed	
R. Gard (62)	France	incision	widening, aggradation of fines	x		
R. Doubs (62)	France	incision		x		
W. Branch Little River (pers. comm Cahoon, 1999)	Vermont			x	bridge undermined, footings exposed	

APPENDIX A SECTION 2.0

LITERATURE SEARCH

Notes from Professionals in the field Morphological Impacts of In-Stream Gravel Extraction

Professionals contacted for phone interviews:
These are my notes, from phone and e-mail conversations with various people. The comments listed underneath each person are their pertinent opinions.

Luna Leopold:
said to contact Bill Trush and Scott McBain

R. McKuen:
not his field

Gordon Wolman:
said to contact Matt Kondolf, Bill Emmett, Gordon Grant, Karen Prestegaard, and Martin Johnson, gave me contact phone #s and e-mails for some of them

Gordon Grant:
gone till feb. 8, sent e-mail information, will send more

Matt Kondolf:
sent all his papers, said to contact David Sear. "determine 'natural bedload- if the river is not mined more than the replenishment rate (the 'bedload transport rate), than mining should be sustainable-BUT- will still have downstream effects of reduced sediment supply downstream. He thinks that 'safe yield' is an illusory concept because of annual changes-there is no annual average sediment yield from year to year.
-mining in the channel itself has the biggest impacts, get incision up and down stream

P Klingemann:
I have been involved in several gravel-mining activities over the years.
We prepared a report in 1995 that summarizes several items that may be of interest to you
The report appears in two volumes:
Gravel Disturbance Impacts on Salmon Habitat and Stream Health
Volume I: Summary Report
Volume II: Technical Background Report
Authors -- Williamson, Bella, Beschta, Grant, Klingeman, Li and Nelson
Copies of the report may be obtained from the project sponsor:
Oregon division of state Lands
775 Summer Street NE
Salem OR 97310-1337
(503) 378-3805
The work was done at the behest of the State Legislature to address salmon habitat and fill-removal activities in state waterways (navigable streams and other where ODSL issues fill-removal permits). We developed a literature review and did considerable work involving our own ideas and experiences.

In addition, I have made some conference presentations on the topic and related topics at ASCE Water resource Engineering conferences since 1995. These appear in the various proceedings and probably are available to you through civil engineering acquaintances or at technical libraries (U. Vermont library or civil engineering department?).

Matt Kondolf has a chapter in our publication: Gravel-bed Rivers in the Environment. This is available from Water Resources Publications (Colorado). They have a web page:

http://www.waterplus.com/wrp

You can see the contents of the book on the web page and decide if there is something of interest. depending on your professional background, there may also be several other chapters of interest to you dealing with rivers and watersheds.

Joan Florsheim:
I am mailing you a reprint of my paper on gravel extraction on the Russian River (Florsheim, J., Goodwin, P., and L. Marcus. 1998. Geomorphic effects of gravel extraction in the Russian River, California. In Bobrowsky, Peter. T. (ed). Aggregate Resources: A Global Perspective. A. A. Balkema Publishers, The Netherlands, pp. 87-99).

One other reference that might be useful to you is a letter written by the Federal Highway Administration (FHWA) to the California Department of Transportation (Caltrans) after 17 bridges failed during the 1995 storms in CA. The letter suggested that Federal emergency dollars would no longer be provided to replace highway bridges that failed because local agencies permitted excessive gravel extraction. Dennis Slota, Director of the Mendocino County Water Agency could provide you with some information on how the gravel mining issue has played out in Mendocino County (slota@pacific.net). I worked with Dennis on two gravel management plans for rivers in Mendocino County (Garcia and Upper Russian), both of which recommended an eventual phase-out of extraction because of geomorphic change and habitat loss associated with extraction.

Dave Norman:
Washington geology. Sent many studies, including his recent article in Washington Geology, and the publication on Best Management Practices for in-stream gravel mining. He wrote: try the NMFS gravel extraction policy at the following address
http://swr.ucsd.edu/hcd/gravelsw.htm

Ken Bates:
Washington fish and wildlife sent a list of references, and studies. Upstream impacts are not documented but after scalping there is a change of hydrologic profile, you get a headcut entrenched or incised through the upstream riffles at crossover bars, slots are cut in channel and that is the beginning of the loss of stabilization. He has seen this in 3-4 locations. Don’t get fish spawning, they relocate to less desirable area. Rivulets form through upstream riffle, they

concentrate flow and lower the pool being retained by the riffle. Aware of study on Puyalup River which looked at different parameters, the study was not statistically conclusive, but observed a change in the backchannel areas upstream of bars, increased homogeneity of channel. On point bars at the downstream end there is usually a backwater channel pool- that pool is critical to salmon and is usually lost at the site of gravel removal, when the bar rebuilds the backchannel is lost. Habitat is critical from year to year, 80% of rearing fish are found in backwater channels-lose channel diversity, pool/riffle structure at extraction site, dewaters the pools upstream-makes a trapezoidal channel. Aware of Alaska study and Kondolf's work. He's been writing a draft guidance for permitting agencies. He is trying to get a handle on flood management, he is curious to know about long term effects on the channel shape and capacity. Wants to know how channel responds to 'hungry water'.
Ken wrote:
From: Ken Bates <BATESKMB@dfw.wa.gov>

This issue of flood benefits of gravel mining is very controversial. Not only are the physical effects debatable, the purpose of flood management triggers funding and permitting as well as emotional and political issues.

We argue all the time about the flood hazard benefits of gravel mining. There are four different arguments people commonly take. I've listed them (and their limitations) in order of sophistication and merit (from my point of view):

1. Every rock that is removed from the river provides that much more channel capacity. This assumes a static (in time and space) channel situation and a one-dimensional model of a river cross section.
2. Digging a hole in the riverbed does not increase capacity; you can dig a hole to China but it won't decrease flooding. If there is any benefit of removal, it's gone before the peak of the next flood arrives as sediment refills the excavation. This advances the discussion to two dimensions. It accurately assumes the water surface is controlled by the downstream channel rather than the cross section.
3. Material removed from the channel will not migrate downstream and therefore the downstream controlling channel will at least not decrease in capacity and may gradually and eventually increase in capacity thereby lowering the hydraulic profile.
4. An alluvial channel will evolve to fit its sediment input and hydrology. A channel depleted of bed material input will evolve to fit the condition of decreased bed material. That evolution may lead to a deeper but more narrow channel and there may be no difference in flood water elevation.

The point of this series of arguments is that it is a very complex issue of four dimensional hydraulics (depth of water, channel cross section, downstream, time).

Your question is "are there any good studies?" There are many prediction model studies and a few monitoring of effects but no cause and effect studies that I am aware of. Most of the studies are good but I haven't seen one that goes beyond argument Number 2 above. Beyond that, geomorphic analysis and/or long term monitoring are needed. I'm not familiar with any such work being done. We need a good geomorphologist studying a river reach that has a documented historical removal rate and a long period of flow records and gauging ratings.

Bryan Collins: no luck

David Rosgen: no luck

Bill Langer:
USGS, geologist looking at aggregates, he wrote
There are a number of sources of information regarding instream mining. The problem is that the impacts from instream mining are VERY sensitive to local conditions. In the Pacific northwest, instream mining is in most cases considered to be a serious problem. Part of the reason for this is the importance of the fishing industry and the presence of salmon that need the streams for spawning. However, there are places in the area where mining appears to be taking place with no significant impact on the fish habitat. Keep in mind that the Pacific northwest streams commonly are high energy streams with very coarse substrate. Many are controlled with dams, which may actually be a bigger cause of concern that instream mining.
search the literature for G.M. Kondolf, ...
search for for B.D. Collins.

In the southeast US along the Gulf Coastal Plain the presence of numerous, closely spaced, and ILLEGAL instream mines have caused problems. If you search the literature for J. Mossa you will find numerous references to instream mining in that part of the world.

Keep in mind that those streams are primarily sand, and are commonly low energy, except during flooding. Joann Mossa also has a web page. The URL is: http://web.geog.ufl.edu/faculty/joann_mossa.html

Steve Filipek has done some work on instream mining in Arkansas. His email is sfilipek@agfc.state.ar.us

There are many parts of the US and the rest of the world where instream mining can take place with little or no significant impacts to the environment. Jiongxin documented how a river with sand over a coarse substrate will stop eroding when the river hits the coarse layer. In Colorado Front Range rivers that appears to be a similar case. Such may also be the case in Vermont. The concept would be that rivers in Vermont (as here in the Front Range) were deposited by glacial meltwater streams. Those streams had a much higher competence than the streams of today. Therefore, the modern streams are incapable of moving around the large gravels that exist in the stream beds. Of coarse, mining would have to be carefully planned and monitored. The reference is:

Jiongxin, Xu, 1996, Underlying gravel layers in a large sand bed river and their influence on downstream-dam channel adjustment: Geomorphology, v. 17, n. 4, p. 351-360.

Piégay and Peiry documented how a river in France that had been experiencing extensive erosion due to instream mining recovered after mining was reduced to levels below the accretion rate of the stream. That reference is:

Piégay, H., and Peiry, J.L., 1997, Long profile evolution of a mountain stream in relation to gravel load management - Example of the Middle Griffe River (French Alps): Environmental Management, v. 21, n. 6, p. 909-919.

Washington Geology Vol. 26, No. 2/3 September 1998. It has 2 very good articles about instream mining - one about problems, one about solutions!

Fred Janssen:
The Southern Division of the American Fisheries Society web site is at http://www.sdafs.org, this contains abstracts on impacts of sand and gravel extraction

Steve Filipek: wrote:
Today an approximately 1.2 KG package with various and sundry reports, citations, and a video even on gravel mining was sent out and should be heading your way. Sorry it took so long but as I say in the letter, because of what we have gone through here in Arkansas we have some physical, morphological, biological and economic examples and experience to draw from. I would be happy, however, to answer any questions that you have in a more timely manner considering the holidays, instream flow field work, etc. are in the past.

April Layher: wrote
If you saw the article which I co-authored in the Nov. 1998 issue of Fisheries on Sand and Gravel Mining, you should find a number of sources listed in the back. I will also forward your message to several folks who might be able to help you too.
Steve Filipek sfilipek@agfc.state.ar.us
Dr. Matt Kondolf gkondolf@aol.com (he has some wonderful examples of how CA streams have been trashed by mining.

Frank Magilligan:
Dartmouth works with Keith Nislow aquatic biologist, did work on Hancock Branch of White

River, trying to tie together morphological and biological impacts.

Tom Dunne:
sent articles, misses Sleepers River

Dan McKinley:
Green Mountain Forest Service, sent cross-sectional information from part of upper White River

Scott McBain:
sent reference list. Works with in-stream gravel mining in California to help county to develop guidelines. Working on study for National Marine Fisheries Service for in-stream and terrace gravel mining
Scott does lots of channel restoration cleaning up after gravel miners. Gravel impacts may take 5-10 years to develop. Scott has written a lot on natural channel design, trying to fix old pits and give the channel a riparian corridor. Gravel mining has significant effects, down-cutting, infrastructure impacts, reduction of groundwater level, loss of channel migration, loss of flood-plain building. Pit mining traps all the bed load and depletes downstream gravel supply. "Scraping and skinning 1 ft above the low water surface means that there is no bankfull channel left, will also lose riparian buffer. He sees impacts with removal of 100s and 1000s of yards. Don't really know how to extract gravel to minimize impacts, mostly know how to do it wrong.
Sent file of references c:\eudora\attach\Mining.doc"
Lori,

The following gravel mining references are from our literature database.

Scott

Collins, B. and T. Dunne (1987). Assessing the effects of gravel harvesting on river morphology and sediment transport: a guide for planners. Seattle, State of Washington Department of Ecology.

Collins, B. and T. Dunne (1990). Fluvial geomorphology and river-gravel mining: a guide for planners, case studies included. Sacamento, California Department of Conservation Division of Mines and Geology.

Klein, R. and G. M. Kondolf (1994). Lower Eel and Van Duzen Rivers: Description of necessary components for development of aggregate resource management plan and action plan for implementation.

Kondolf, G. M. (1993). "Geomorphic and environmental effects on instream gravel mining." Landscape and Urban Planning **28**(1994): 225-243.

Kondolf, G. M. (1995). "Managing bedload sediment in regulated rivers: examples from California, U.S.A." Natural and Anthropogenic Influences in Fluvial Geomorphology **Geophysical Monograph 89**: 165-176.

Meador, M. R. and A. O. Layher (1998). "Instream sand and gravel mining: Environmental issues and

regulatory process in the United States." Fisheries **23**(11): 6-13.

Swanson, M. (1993). Hydrologic and geomorphic impact analysis of the proposed Bed Rock, Inc. gravel extraction plan on the Garcia River, Mendocino County, CA. Santa Cruz.

Lyle Stefan:
NRCS no studies on his own, uses own knowledge, only thing printed is White River, Vermont study. Common impacts: head cuts migrate upstream, bank erosion is accelerated on opposite side. When bars are scalped no confinement for low-flow channel, flow drops sediment in wide braided reach so it accelerates bank erosion.

On white River it looked like gravel mining helped to change a C channel (Rosgen) to B channel. Channel straightened to a cobble bottom, run stream with no pools. The reach was stabilized, but it lost all of its morphology. The cobble bars that were pushed to the sides acted as rip-rap, the flood plain break to define bank full channel was lost. Gravel mining in White River major cause of bank erosion.

Bill Trush:
Working on NMFS in-stream gravel mining study with Scott McBain and Aldaron Laird. Said most studies are post-mortems, and don't help to learn how to do it right. He works on a committee to allocate gravel and make the best guess of 'safe yield'. Said that Randy Klein has reports on 'sustained yield'. Randy did long-term assessment on gravel-mining found impacts included bed lowering and loss of bar features. Felt like most people are operating in a huge realm of ignorance trying to extract less than the sustained yield. Says that thalweg profiles are crucial for monitoring, he is doing statistical analysis to fit regressions to thalweg profiles, and combining it with a correlation to the river ecosystems, looking at mean, variance, skew..Variation is a tool in determining residuals-if it fits actual value and regressed value- there is a subset of thalweg measurements at the top of riffles, he looks at variability in downcutting and degradation, playing around with how deep does flow need to be over the bar until deposition occurs, also looks at changes in bedload due to dams. He doesn't agree with the school of replenishment/extraction or 'geomorphic baselining' or redlining. This does not account for downstream impacts, or allow the river to aggrade and degrade according to natural features. He likes 'sustained yield' school. They recommend extracting to 80% of sustained yield, they use a bedload transport model. Works with Andre Lehre. They try to maintain confinement of channel

Andre Lehre
no luck

Aldaron Laird:
doing literature search for NMFS on impacts of in-stream gravel mining. Said there is a lot of work on changes in channel morphology, and flood responses and infrastructure impacts. In Yolo and Sonoma counties the results of increased regulation, monitoring and compliance is that there is less in-stream mining.
-Skimming has greater impact on channel morphology than in-stream pits. In Oregon a removal

operation of 20,000 cy is huge, find that with extraction rates under 20,000 yds have significant channel adjustments quickly. During his literature search he has contacted three states and counties and tries to get regulatory information and studies. Said to talk to Bill Langer, Washington State, Bob Curry at UC Santa Cruz and Randy Klein
-said 'red-line concept doesn't work because it takes a couple of years for the morphology to respond
-see his reference list at end of this appendix

Bob Curry:
has a huge amount of 'grey' literature. For example, has 12 shelf feet on the Russian river.. Lots of articles in California Geology. Said to talk to Joan Florsheim. Mentioned work in New York state on sediment budget analysis by land use, mostly concerned about water quality for NYC drinking water, (never sent reference or contacts). Said NRCS did a study in mid-west said that with a greater than 30 year return flood that channel scour occurred and gravel mining did not increase channel capacity at all (never sent reference). NRCS manual was very mid-west focused. Bob is presently teaching a short course with Rosgen. Bob sponsored symposium on flooding and in-stream gravel mining (no proceedings available). Said to talk to Jeff Haltner at Phillip Williams and Assc. for info on flooding vs. gravel extraction (no success finding him)

Jeff Haltner:
no luck

Randy Klein:
Sent his and Bill Trush's unpublished reports which suggest design specs and specific types of mining (reports received) to reduce impact. Doesn't recommend trenching because of negative impacts of trenching, says to use bar-skimming that is near the annual replenishment rate of mined gravel. Avoid gravel extraction at heads of bars and meanders to minimize meander cutoffs. Recommends using 'sustained yield: combined with analysis of cumulative affects. Take a long-term sediment budget and vary it based on years hydrology. Doesn't agree with baseline morphology, or redlining approach of Mitch Swansons. Redlines are mostly used with respect to bridges. Redlines should be based on upland scour depths, and not on the low flow channel. Can't have a river wide redline because it ignores the three-dimensional measurements of channels. His papers address bank erosion and flooding. Flooding is not ameliorated by gravel mining. Flooding is really a land use planning issue, don't build in flood zone. Most of the watersheds in his area have been timber harvested (increased sediment supply)
he wrote:
attached is yet another file with Mad River mining prescriptions from 1994. it provides an example of how we've dealt with mining in years of little or no replenishment due to lack of high flows.

David Dunn(formerly of USGS) wrote:
My work for the USGS is still in progress, and really will not address mining in the type of riverine environment that you will find in Vermont. My work is concentrating on sand extraction only from a single stream, the Brazos River. The Brazos is a large, low gradient, incised, sand bed river with very little gravel. The material extraction is primarily sand, with very little gravel. The preferred method of extraction is hydraulic dredging from a barge tethered in the stream. A water/sediment slurry is then piped from the barge to the bank, where the excess water is drained and returned to the stream and the material is washed, screened, and sorted. The dredged holes typically refill quickly once dredging stops--on the order of a couple of months to a few years, depending upon the frequency and duration of high flows.

In the steep (compared to the Brazos), generally smaller (compared to the Brazos) streams you find in Vermont, the larger aggregate sizes are more predominate and the method of extraction is probably quite different. From what I have seen in places like Missouri, drag lines or direct excavation using backhoes or other earth moving equipment are typically used. These methods generally are much more invasive and destructive to the riverine environment than the methods utilized on the Brazos.

The American Fisheries Society had a symposium in San Antonio on sand and gravel mining a few years ago. Several of the speakers were from places like Missouri, Arkansas, and Tennessee where the typically more invasive methods are used and have severely damaged riverine environments. I was actually quite shocked that those activities were being permitted.

If you have not contacted him, you should try to get in touch with Rob Jacobson of the USGS in Missouri. View his web page at:

http://wwwdmorll.er.usgs.gov/~jacobson/project.html

Other than that, I don't have much to help you with regarding gravel extraction. Please call me if you feel you want to discuss anything else.

Robb Jacobson:
USGS, Missouri. There are more studies on how in-stream gravel extractions affects aquatic habitats. Rob studied land use change, logging at the turn of century, grazing, loss of riparian vegetation...Said to contact Mike Roell at Missouri Dept of Conservation. Mentioned Alaska study. Said in-stream gravel mining in Mo, formerly under Army Cof E, changing permitting system now. Sent his studies

Mike Roell:
Missouri Department of Conservation. He will be finished by end of march on literature review and study of in-stream gravel mining, sent draft copies of reports.
-Attached are the two files we discussed on the phone. Feel free to call if you want to discuss interpretation or other aspects. Good luck with your challenge!

Joann Mossa: wrote
Interesting that Europe is becoming a center of gravel people. These are some citations, with the most recent and relevant ones listed first. I wish you success. Please let me know if I can help further.

Mossa, J., and McLean, M.B., 1997, Channel planform and land cover changes on a mined river floodplain: Amite River, Louisiana, USA: Applied Geography, v. 17(1), pp. 43-54.

Mossa, J., 1995, Sand and gravel mining in the Amite River flood plain, pp. 326-360 in John. C.J., and Autin, W.J., eds., Guidebook of Geological Excursions, Geological Society of America, 1995 Annual Meeting, New Orleans, LA, 360 pp.

Mossa, J. and Autin, W.J., 1998, Geographic and geologic aspects of aggregate production in Louisiana, in Bobrowsky, P., ed., Aggregate Resources: A Global Perspective, A. Balkema, Rotterdam, The Netherlands, pp. 439-63.

Autin, W.J., and Mossa, J., 1997, Environmental systems approach to basin management: Future alternatives in the Amite River basin, pp. 83-89 in Floodplain Management in a Mult-Faceted World, Proceedings of the 21st Annual Meeting of the National Association of State Floodplain Managers.

Vernon, R.D., Autin, W.J., and Mossa, J., 1992, Developing a floodplain sand and gravel mine reclamation program in the Amite River basin of Louisiana, pp. 240-5 in Proceedings of the Intl. Symposium on Land Reclamation, American Society of Agricultural Engineers, St. Joseph, MI.

Mossa, J., 1985, Management of floodplain sand and gravel mining: Flood Hazard Management in the Government and Private Sector, Proceedings of the Ninth Annual Meeting of the National Association of State Floodplain Managers, pp. 321-8.

Barry Cahoon:
Vt ANR. West Branch bridge to Trapp, and other bridges on 108 deeply incised and undermined due to gravel extraction. Mad, West Branch, 3rd branch White, Browns, Huntington and Trout

river hit hard, every bar was mined every year right down to low water level. Each year there would be more gravel. Town highway bridges are designed for Q25, state highway bridges are designed for Q100. Most typical problem is with culverts and inlet head losses. Cursory review of records showed largest extraction volumes of 80 - 100,000 yds. More typically found extraction of 200 - 5,000 yards on multiple bars in same channel.

Cathy Crosset: California Transportation wrote:
From: Cathy_Avila@dot.ca.gov
Following is the abstract
-- our e-mail system does not allow us to send really big files (and my
thesis is a really big file). Take a look at the abstract and if you would
like a (tree killing) copy of the thesis, let me know and I will mail one
to you (after I am back in the office 2/8). I am curious as to what type of mining has been going on in VT -- I haven't seen much literature outside of Nevada, Arizona, Washington and California.

Cathy Crosset: California Transportation wrote:
From: Cathy_Avila@dot.ca.gov

Abstract

Gravel mining in active channels can impose significant harm to instream structures. Extraction exceeding replenishment generally causes riverbed degradation exposing bridge foundations. Such undermining of structure foundations is extremely costly to repair. Most current regulatory policies are too rigid to adequately address the uncertainties associated with the state of the art of sediment transport and geomorphology. However, economic or financial inducements can provide a flexible and efficient alternative to regulation. Economic inducements internalize the costs imposed by the aggregate mining industry, providing operators with the incentive to minimize damage to infrastructure.

Paul Hartfield wrote:

> Lori: attached are two bibliographies that may be of use. I have copies of most of these, but it will take me some time to copy and send. Please let me know how else I can help. I'll copy pertinent portions if you need me to. Paul