An Assessment of Fall Chinook Salmon (*Oncorhynchus tschawytscha*) Spawning Habitat for Present and Pre-impoundment River Conditions in a Section of the John Day Reservoir, Columbia River

by

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Abstract

The Columbia River system in the Pacific Northwest is currently comprised of a series of reservoirs, resulting from regulation of river flow due to a series of hydroelectric dams. A return to pre-dam conditions might improve salmon (*Oncorhynchus* sp.) survival rates and increase migration efficiency. This study modeled both historic and current river conditions for a part of a reservoir on the Columbia River in order to characterize the impact of a river reservoir drawdown to historic (pre-dam) water levels. The study area is a 48-kilometer stretch of the John Day reservoir in the middle Columbia region that is currently being considered for water level drawdown. Within this study, historic pre-dam aerial and oblique photographs and hard-copy bathymetric survey maps were incorporated into a GIS (Geographic Information System) to characterize the wetted perimeter of the river, substrate distribution, water depth, and overall channel morphology of the original channel. The current river conditions were also characterized using digital orthophotos, hydrographic survey data, and fisheries sampling information. The spatial distribution of habitat in the historic and current river channels were compared using existing knowledge of salmonid behavior and habitat requirements in large river systems for adult spawning activities. The results of this study can be used to indicate similarities and differences between historic and present conditions, which may help designate how well a "return to the river" drawdown concept could be implemented to achieve the desired increase in preferred salmon habitats.

Introduction

The Columbia River system in the Pacific Northwest is currently comprised of a series of reservoirs resulting from the construction of a series of hydroelectric dams. The conversion of the Columbia River from a free-flowing riverine system to a series of interconnected lakes has resulted in major modifications in the native vegetation, fish species, water temperature, sediment distribution, flow regime, and water depth associated with the river channel. A major impact of the dams has been alteration of the river as a spawning, rearing, and migratory corridor for many stocks of four species of Pacific salmon.

A primary concern is the passage of juvenile salmon through a series of dams and reservoirs during the course of their seaward migration as smolts. The chinook salmon (*Oncorhynchus tschawytscha*) is the primary species of concern, particulary the fall (race) of chinook salmon. The decline in Snake River fall chinook resulted in their listing as a threatened species under the Endangered Species Act in 1992 (NMFS, 1992). Mortality rates associated with dam passage are considered to have a critical impact on overall smolt survival rates. Another indirect effect of the reservoir system is the increased travel time in the pools between dams, and the influence of this on fish health and timing of estuary arrival. The physical conditions of the impounded river result in a longer exposure of juvenile salmon to predation and higher than optimal water temperatures, each of which may decrease survival rates. Some exotic fish and vegetation species are fairly successful in regulated rivers, and in the Columbia River these include additional predators which formerly did not exist in the system. Because of the artificial fluctuations in discharge that exist in regulated rivers, resident species are typically replaced by generalist species, including predator species, which are more tolerant of frequent variations in river flow (Poff et. al., 1997). Also, there is some evidence that the lower the gradient of the river, such as is often found in regulated rivers, the greater the proportion of non-salmonid species (Itveit and Styrvold, 1984). Slow water velocity, shallow nearshore areas, and high water temperatures are considered optimal for predator fish species (piscivores); and total numbers of piscivores have been found to be greater in some reservoirs than in some free-flowing stretches of rivers (Key et al., 1996).

The John Day Dam was constructed in 1968, and created the John Day Reservoir upstream. It is the longest reservoir (122.2 kilometers) in the lower Columbia River and is the only one in the lower Columbia River that has water storage capabilities (Figure 1). The John Day Reservoir is the only migration corridor for anadromous salmonids from the middle and upper reaches of the Columbia and its tributaries, and the entire Snake River system. It currently functions as a rearing area for fall chinook salmon, an outmigration corridor for all species of anadromous fish found in the system, and it supports limited fall chinook spawning activities (Poe, pers. comm.).

Before impoundment, this stretch of river supported significant fall chinook spawning (Fulton, 1968; USACOE, 1951). Due to the perceived risks to juvenile salmon associated with this reservoir, the U.S. Army Corps of Engineers (USACOE), at the suggestion of an

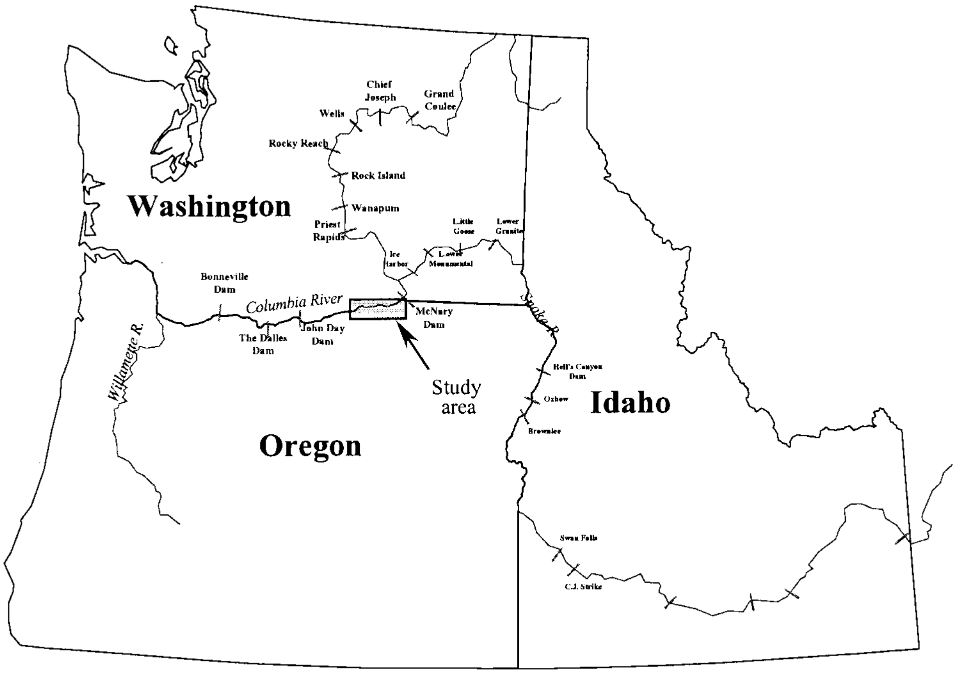


Figure 1. Location of study area and the major dams in the Columbia River system.
Source: Pacific Northwest River Basins Commission 1971

independent scientific council, is considering a drawdown of the reservoir to create a river channel that more closely represents physical conditions of the pre-impoundment river. The drawdown scheme is an element of a "return to the river" plan, in which an independent scientific group (ISG) has concluded that survival rates for juvenile salmon in the system will improve the system is returned to an environment more closely resembling pre-impoundment conditions (ISG, 1996). Regulation of dam operations and water levels can enable natural processes in the river system to re-establish in regulated systems. The re-establishment of natural processes may in turn, allow the recovery of certain populations, such as salmonids (Stanford et al 1996).

A drawdown would lower the water level to either spillway crest (215-220 feet above mean sea level) or natural river (160 + feet above mean sea level) (USACOE 1997). The natural river option will effectively cause the present channel to retreat into the original channel, thereby creating physical and hydraulic conditions more similar to a natural river.

The primary objective of this study is to model the physical features and morphology of the original river channel as they existed before the dams were in place. Recreating the original channel will make it possible to identify areas of the river which meet physical criteria for fall chinook spawning and rearing habitat. Spawning habitat is the most applicable for this study because many quantitative studies have been done on the physical limitations to spawning habitat, while rearing habitat is more difficult to quantify. Physical requirements for fall chinook salmon spawning have been studied for free-flowing sections of the Columbia and Snake Rivers, so it is possible to define limits for the distribution of spawning redds (Chapman et al. 1983; Chapman, 1943; Conner et al 1994; Geist, 1998; Geist and Dauble, 1998; Swan, 1989; Swan et al 1988; Watson, 1976). Physical criteria for water depth, lateral bed slope, substrate type and velocity known to limit spawning activities in free-flowing rivers were used in this study to quantify differences between the available spawning habitat and that which existed before the dams were in place. Once satisfactory criteria are determined for juvenile rearing conditions in riverine systems, these can be applied to the river model created in this study.

Reconstruction of historic river conditions will help assess changes expected to occur in the event of a river drawdown regarding the distribution of essential habitat features for salmonids. This study chronicles historical information available on the distribution of chinook salmon in the river, describes and quantifies the physical features of the pre and post-impoundment river, and characterizes the spatial distribution of potential fall chinook spawning areas for a section of the John Day reservoir in the Columbia River under pre and post-impoundment conditions. It is limited to the upper half of the reservoir because the influence of water level drawdown will be greater in the upper half of the reservoir (Poe, pers. comm. 1998).

Background Information

Study Area

The study area is located in the Lower Columbia region, between the towns of Boardman and Umatilla, Oregon (Figure 2). The study area extends from Crow Butte, which is 261 river miles (RM) upstream from the mouth of the Columbia River, to the present location of McNary Dam (RM 292). The river in this section is impounded by the John Day Dam (at RM 215.6) creating a reservoir named "Lake Umatilla" or "John Day Reservoir." The water is effectively pooled above John Day Dam, but the pooling effect lessens with increasing distance upstream from the dam. The study area is the upper one-third of the reservoir (the upper 48 kilometer stretch), and the lower 24 kilometers of this area are significantly more impounded than the remainder of the study area.

One major tributary, the Umatilla River, joins the Columbia within the boundaries of the study area at river mile 289, along with a number of minor intermittent tributaries (Figure 2). The Walla Walla River flows into the Columbia approximately 37 kilometers upstream of the eastern boundary of the study area, and the confluence of the Columbia and Snake Rivers is located approximately 52 kilometers upstream of the boundary.

Topography and Geology

The area is distinguished by basalt cliffs and rugged hills, and the river is surrounded by the shrub-steppe headlands which characterize much of the eastern Columbia River

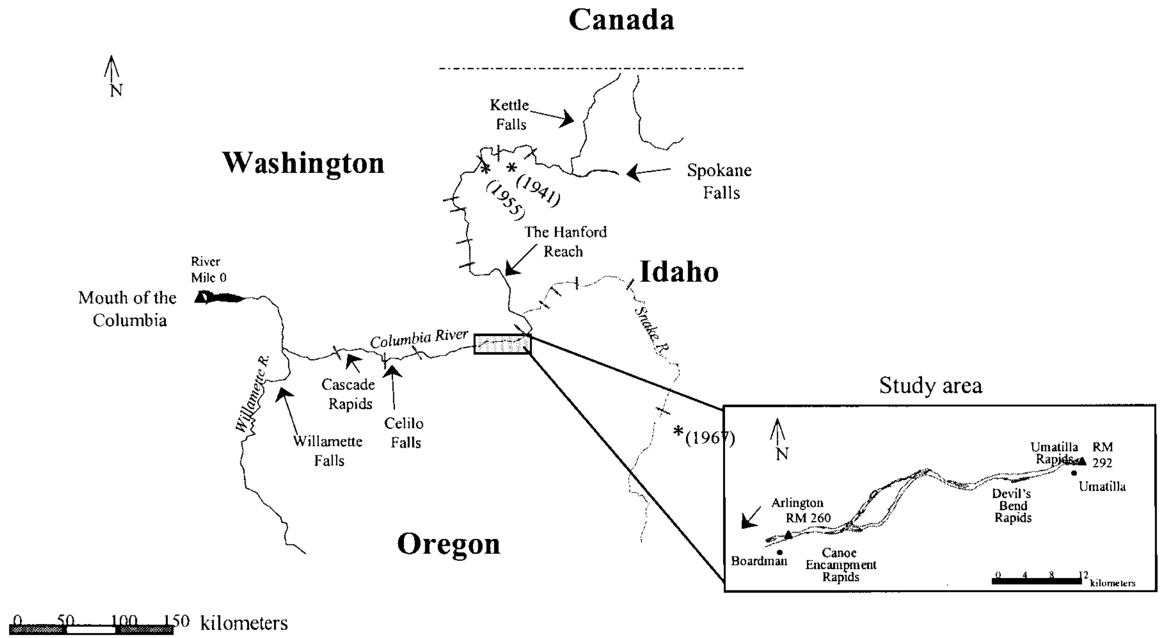


Figure 2. Location of important historical river features for Columbia River salmon. Short lines indicate the current location of dams, many of which inundated the falls and rapids indicated here. The dams with with asterisks completely blocked anadromous fish migration upon completion. The Hanford Reach is currently the last free-flowing section of the Columbia River. The inset shows the river shape of the pre-impoundment study area. Source: Pacific Northwest River Basins Commission 1971.

Gorge. The Columbia River Basalt formation (10 to 16 million years old) forms the river channel and surrounding topography. The composition of the river structure and sediments is shaped by the Missoula Floods, which occurred here 12,000 to 19,000 years BP. During this period of the Ice Age, an ice dam in northern Idaho created glacial Lake Missoula in Western Montana. The repeated cracking of this ice dam and consequent release of Lake Missoula waters resulted in cataclysmic flooding throughout the Columbia River Gorge, downcutting the gorge and depositing the dominant sediments throughout the entire river system (Allen, 1982). The river sediments are primarily comprised of plutonic, igneous, and metamorphic source rocks of the Columbia River Gorge, and additional eolian deposits originating from Eastern Washington and the lower Snake River Basin (Sherwood and Creager, 1990).

The topography of the hills flanking the river is shaped by a structural monocline trending northwesterly across the Columbia River in the vicinity of Wallula, Washington, east of McNary Dam, then rising above to a plateau in the Horse Heaven Hills north of the study area (USACOE, 1951).

Salmon in the Columbia River

Life History of Chinook Salmon in the Columbia River System

Fall chinook salmon in the Columbia River drainage typically spawn in the mainstem of the lower and mid-Columbia, and lower sections of major tributaries (Fulton, 1968). The behavior of present and historic spring and fall chinook populations is believed to be constrained by variations in river temperatures which regulate choice of spawning sites and the incubation and emergence of fry (Miller and Brannon 1982). In the mid-Columbia River, spring chinook typically spawn in the headwaters of tributaries from July to mid-September, and fall chinook typically spawn in mainstem Columbia River areas during late October and early November (Meekin 1963; French and Wahle 1965; Chapman et al. 1982). Timing and behavior of chinook salmon spawning in the Columbia River are closely associated with the changing longitudinal gradient of river temperatures, which initially decrease to optimal levels in the tributaries (for the earlier spring chinook), then later in mainstem areas of the Columbia (for the fall chinook) (Mullan, 1985).

Salmon appearing at the dams intermediary to the fall and spring chinook runs are considered by some to be summer chinook. These fish are believed to use diverse spawning strategies, and utilize habitats in headwater and mainstem areas. This may be one reason this particular race of chinook salmon is considered to be the primary source for the historical world-renowned abundant chinook salmon runs of the Columbia River in the nineteenth century (Thompson, 1951). Historically, chinook salmon entered the river continuously from April through September, with a peak in numbers between June 10-20, and lower numbers entering on either side of the curve in April and late September (Thompson, 1951). The main portion of the run (summer chinook) was depleted by the early 1900s, leaving the remnant spring and fall chinook as the extant primary runs of salmon in this century (Thompson, 1951).

Fall chinook juveniles typically leave emergence sites to rear in downstream reservoirs as young of the year in the spring, while spring chinook juveniles more commonly rear in the smaller tributaries where they emerged for a year prior to migrating to the ocean. The summer chinook is believed to use strategies similar to both fall and spring runs for rearing (Healey, 1991). Chinook salmon usually stay out to sea for three to five years before returning to their natal streams (Healey, 1991).

Historical Fisheries

Historically, the Columbia River produced more chinook salmon than any other stream in the world (Washington Department of Fisheries, 1959). European settlement of the area began in the early 1800s, and commercial exportation of salmon from the Columbia River began in the 1830s. The first cannery was established on the river in 1866. The abundant migrating chinook (*Oncorhynchus tschawytscha*), sockeye (*Oncorhynchus nerka*), steelhead (*Oncorhynchus mykiss*), chum (*Oncorhynchus keta*) and coho (*Oncorhynchus kisutch*) were most commonly exploited using fish wheels, gillnets, seines and trolls. These methods were so successful that in 1883 there were fifty canneries established on the banks of the lower river (Netboy, 1980). The fish wheels were highly efficient because of their placement in areas with deep, swift water. Often, artificial channels were created to trap and guide more adult salmon into the wheel (Evermann and Meek, 1898).

Non-Native American commercial fishing was done throughout the lower river downstream from Celilo Falls, while Native American fishing efforts in the lower river were focused at Cascade Rapids (current location of Cascade Locks, Oregon), Celilo Falls (upstream of The Dalles, Oregon), and Willamette Falls (current location of Oregon City, Oregon) (Figure 2). Native American fishing efforts in the upper river were concentrated at Kettle Falls, Spokane River Falls, and in the San Poil River. In 1883 a peak salmon catch of 43,000,000 pounds was attained, including chinook, coho, sockeye, chum and steelhead (USACOE, 1952).

Chinook salmon were the largest and most abundant of the five salmon species found in the system and were the primary catch. The average annual harvest of chinook salmon in the 1800s was about 30 million pounds (1.5 million chinook salmon if estimating 20 pounds per salmon). Estimates derived from distribution of habitat in the river system have predicted that 250,000 of these chinook may have been heading to the mid-Columbia River and another 250,000 heading for the upper river above the present location of Grand Coulee Dam (Haas, 1975). The remaining fish were possibly going to locations in the lower Columbia and tributaries.

Salmon populations waned in response to pressures including destruction of spawning areas, commercial fishing, logging operations, and the completion of Bonneville Dam in 1938. The total catch in 1947 had declined to 21,220,862 pounds of fish (USACOE, 1952). Chinook salmon populations were the first to decline, followed by the other species, coho, sockeye, chum, and steelhead. In the 1930s, fish wheels were banned and stronger limitations placed on the fisheries because of declining populations of all species (Netboy, 1980).

Historic Distribution of Salmon

Chinook Salmon

A number of important chinook salmon spawning areas were located in the main channel of the river and in tributaries upstream of Celilo Falls. The entire Columbia River below the mouth of the Yakima River was a migration corridor to all upriver spawners, and the stretch between the Yakima and Celilo Falls was important for mainstem spawning (USACOE, 1952) (Figure 2). Important spawning areas for spring and summer chinook included the John Day River, Umatilla River, Snake River tributaries, the Walla Walla River sytem, and the entire area upstream of Chief Joseph Dam. (Fulton, 1968). Other important production areas were in the mainstem above the current location of The Dalles, McNary and Rocky Reach Dams, and in the Snake River from upstream of the current site of Ice Harbor pool to the Hells Canyon dam site. Fall chinook spawning in an unimpounded section of the Hanford Reach - located between McNary and Priest Rapids Dams - increased in the 1960s after construction of the Priest Rapids Dam. This increase is generally attributed to upstream translocation of fish whose spawning grounds had been inundated by the construction of dams - The Dalles, John Day, and McNary - downstream of the Hanford Reach (Watson, 1976).

Fulton (1968) reported that there was a large population of fall chinook salmon which spawned in the 160 kilometer stretch of river downstream from McNary Dam, extending to the current location of Miller's Island, approximately 18 kilometers downstream of John Day Dam. Based on dam returns during 1957-1960, the top three most important areas for fall chinook production were: 1) Snake River, 2) main Columbia River from John Day Dam to McNary Dam, and 3) Spring Creek (hatchery production). Based on the these returns, 34,000 adults used the main Columbia between the current John Day damsite and McNary Dam during this period (Fulton, 1968).

Other Salmon Species

Coho salmon production was concentrated in lower Columbia River tributaries, though there were small runs to the middle and upper Columbia which were destroyed prior to the completion of Grand Coulee Dam in 1948. Coho salmon historically spawned as far upstream as the Spokane River and in the Snake River Basin (Fulton, 1970). Sockeye salmon were found in large numbers in the system and were distributed in eight lake systems within the middle and upper Columbia region. In the latter part of the nineteenth century, dams placed on tributaries blocked access to the nursery lakes these fish required for spawning (Mullan, 1985). Steelhead trout were widely dispersed and spawned in the Snake River Basin and the main Columbia as far upstream as the Canadian border. Chum salmon spawned in lower river tributaries downstream of the current location of John Day Dam (Fulton, 1970).

Current Distribution of Salmon

It is estimated that one-third of salmon and steelhead habitat in the system has been lost because of impassable dams, and a study by Oregon Trout estimated that 200 stock extinctions have occurred in the Columbia River Basin (Northwest Power Planning Council, 1986; Nehlson et al., 1991). This considers only wild fish and not hatchery fish. Of these 200 extinctions, 95 are chinook, 83 are steelhead , 17 are coho, and 12 are extinct stocks of sockeye.

A couple stocks of fall and spring chinook salmon in the lower Columbia River are thought to be extinct, and a number of others are at a high risk of extinction. A high risk population, as defined by Nehlson et al. (1991), is one with declining spawning escapements, and the ratio of fewer than one adult fish returning to spawn for each parent spawner. Many stocks originating from the Snake River system are being considered for threatened or endangered status, and others in this system are at a high risk for extinction. Wild coho salmon stocks are almost extinct upstream of Bonneville Dam, and at a high risk of extinction downstream of the dam.

The Snake River sockeye run is functionally extinct; 96% of sockeye habitat has disappeared or is inaccessible. Chum salmon are currently at a moderate risk of extinction, and represent .5% of the historic population. Steelhead are at a high risk of extinction in the lower river below Bonneville Dam, and runs further upstream in the system are of moderate risk to extinction, or are populations of special concern (Nehlson et al., 1991).

Columbia River Dams and Salmon

The fishery is now influenced by a series of hydroelectric dams on the mainstem river and many of its major tributaries (Figure 3). The first major dam in the system was Rock Island Dam in the mid-Columbia, completed in 1933. Bonneville Dam was completed in 1938 and was followed by the uppermost dam on the Columbia south of Canada, the Grand Coulee Dam in 1941 (Pacific Northwest River Basins Commission, 1971). This dam was too high to allow for fish passage, so it essentially cut off all wild salmon runs originating in Canada and other upstream areas. Because of the decline in commercial fishing yields by the 1940s, hatcheries became important in attempts to boost the falling numbers of the remaining runs of wild salmon. An increase in industrialization and pollution in the lower river also became important factors in the decrease in salmon runs.

Salmon evolved in strictly riverine systems, and reservoir systems differ greatly from these systems. Unregulated rivers typically experience continual channel modification, and features are maintained by the dominant discharges of the system.

The distribution of flows in a regulated river differs from that in an unregulated river in that the magnitude and frequency of high flows and natural flood events are reduced, thus reducing the number of point bars, secondary channels, oxbows, and overall channel

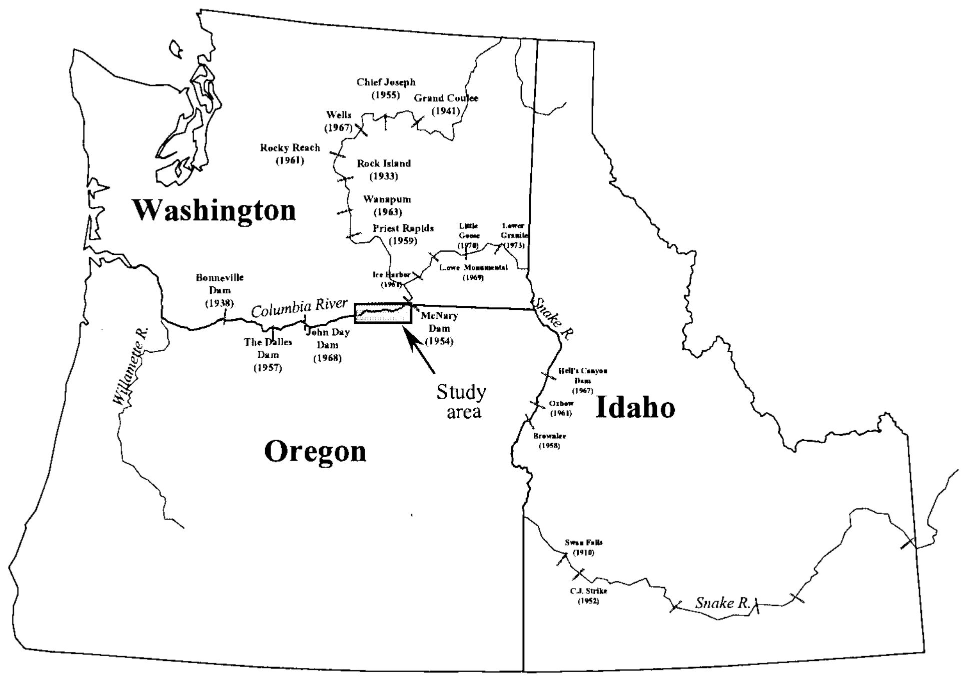


Figure 3. Location of dams on the Columbia and Snake Rivers. The year of completion for each dam is included in parentheses.
Source: NMFS 1995 and Pacific Northwest River Basins Commission 1971

complexity. Dams impact the channel by causing erosion, headcutting of tributaries, and bed armoring (Poff et. al., 1997).

Species of salmon that spawn in smaller tributaries have suffered a loss of spawning habitat due to irrigation, forestry practices, and overgrazing; and salmon that spawn in mainstem or larger tributaries have suffered a loss in spawning habitat because of the laucustrine nature of the new river system. Difficulties for juvenile salmon stem from dam passage when outmigrating to the ocean and in navigating the low velocity pools created by the dams. Some Columbia River adult salmon must pass up to ten dams in returning to natal spawning streams, and Snake River salmon may need to pass as many as eight dams (Netboy, 1980).

Criteria for Fall Chinook Spawning

A number of environmental factors influence the selection and success of spawning sites for chinook salmon: water depth, lateral bed channel slope, gradient, water temperature, substrate - grain size of bed material or sediments , water velocity, and scour effects (Burner, 1951; Vronskiy, 1972; Chapman et. al., 1986; Chapman, 1943; Conner et al., 1994). A model used to predict chinook salmon spawning distribution (Physical Habitat Simulation model [PHABSIM] of the Instream Flow Incremental Methodology [IFIM]) uses physical parameters of water depth, velocity, and substrate size to predict possible spawning areas (Milhous, 1979; Stalnaker, 1979). A number of studies have suggested that a more accurate model should include smaller scale hydraulic features, such as lateral slope, bed scour, and characteristics of the hyporheic zone of the river, and other details relating to geomorphology of the river (Conner et al., 1994; Geist and Dauble, 1998; Geist, 1998).

Limitations for chinook spawning with respect to water depth, substrate and velocity are broad, although more specific ranges are available for particular river systems. In general, for a range of fall chinook populations from different rivers, spawning occurs predominantly in water less than seven meters in depth, and in areas with velocity values ranging from 10 to 150 cm/s (Healey, 1991). However, these values reflect information from various studies using different methodologies. Fall chinook are generally believed to spawn in higher velocity waters than other *Onchorhynchus sp.*, possibly because of their larger size and better ability to cut redds in areas with the coarser gravel found in high velocity areas (Healey, 1991). Substrate requirements are also broad, and reported spawning gravel sizes range from 1.3 to 30 centimeters in diameter (Bell, 1986; Swan et al., 1988; Swan, 1989). Substrates with compositions high in sediments less than 6.4 mm in diameter have been found to reduce the emergence and survival of chinook salmon (Eaton and Bennett, 1996)

Considering spawning criteria for redd locations only in the Hanford Reach of the Columbia River, substrates range from 5 to 30 cm in diameter, water depth ranges from 0.3 to 9.0 meters, and velocities range from 0.4 to 2.0 meters per second (Swan et. al., 1988, Swan 1989, Chapman et. al., 1983). Percentage of lateral bed slope is another feature which has been correlated with redd locations on the Columbia and Snake Rivers.

Fall chinook redds are commonly associated with lateral slopes ranging from 0 to 5 percent (Geist 1998; Conner et al. 1994).

Large-scale geomorphic features of rivers also can influence spawning locations. Dauble and Watson (1990) found that redd locations in the Hanford Reach of the Columbia River were distributed more commonly in areas with complex channel patterns. They have also been found to occur more commonly in transition areas between pools and riffles (Bjornn and Reiser, 1991) and at the heads of riffles, preceding the crests of rapids in areas of high subgravel flow (Vronskiy, 1972). There is also some evidence that clustering of redds may be related to physical conditions associated with the hyporheic zone of the river. Hyporheic zones are distinguished as the subsurface section of the river where there is a mixture of groundwater and surface water. Downwelling or upwelling areas of the river are areas in which groundwater moves either in or out of this zone (Geist and Dauble, 1998). These areas occur more commonly in river reaches with complex channel patterns (Brunke and Gonser, 1997) and may be more commonly selected by adults because of the increased water flow and consequent high oxygenation through the bed materials (Iwamoto et al. 1978; Geist and Dauble 1998).

Methods

The main data sources used in the habitat analysis are listed in Table 1. The nature of this study is more qualitative than quantitative due to limitations in corresponding data sets for pre and post-impoundment conditions. Underwater substrate information is nonexistent for historic conditions, and the substrate information that exists for current conditions is based on limited sampling data. The hardcopy maps used for most of the historical information contain some degree of error originating from the age and condition of the original maps and survey techniques. Additional background information and details on data processing and analysis for intermediate steps (depth, channel morphology, substrate, and velocity) are included in Appendix A.

Hydrography

The data source for pre-impoundment hydrography are War Department (USACOE) maps, which were originally created from surveys conducted on the Columbia River in the 1930s for navigation and hydroelectric development purposes (Appendix A1). The hydrographic survey data used to represent current conditions are taken from a recent (1994) survey conducted by the U.S. Army Corps of Engineers for navigational purposes.

Data from both sources were incorporated into continuous surfaces (GRID coverages) representing water depths and riverbed elevations for both time periods (Appendix A2). The discharge represented by the pre-impoundment survey maps is documented as the

Table \ . Primary data sources used for digital analysis.

Data Source	Scale	Source Information	Original Format	Final Format
War Department (COE) Hydrographic Survey Maps - 1935	1:2,000 and 1:4,000	point/transect depth data and other shoreline and river features	hardcopy maps	continuous river surface
USACOE Hydrographic Survey data - 1994	unknown	point/transect depth data	digital ASCII file	continuous river surface
1944 aerial photographs	1:20,000	black and white aerial photographs	copies from original prints	digital rectified, georeferenced photographs
1994 aerial orthophotos	1:24,000	black and white aerial photographs	digital orthophotos	no processing
Digitized shoreline features - Columbia River Research Laboratory - 1990	unknown	digitized shorelines and river features created from NOAA navigation charts	digital - GIS coverage	no processing
substrate data	unknown	river sampled and divided into polygons representing 11 substrate types for study area	digital - GIS coverage	reclassification

mean low water plane for the period, which was interpreted as the low water discharge between 1930 through 1940 (between 50 and 100 kcfs). The current river was modeled at a discharge of 50 kcfs, which represents a mean low discharge through McNary and John Day dams with a minimum operating pool (at 257 MSL in the forebay of John Day Dam). The river under these conditions has the greatest quantity of shallow water habitat, and therefore would give the most conservative estimate of spawning habitat loss between the two time periods.

The spatial data structure chosen to model bed elevations and other morphological features were grids, because of the flexibility of computations with grid surfaces. Triangulated Irregular Network (TIN) surfaces are considered in some situations to better represent elevational features, but were not used in this study because of the inflexibility of TIN data structures in arithmetic functions (Wright, pers. comm.).

Classification of Habitat Features

River geomorphic features, velocity, and water depth can be used to classify rivers into habitat units of pools, riffles, and runs (Bovee, 1986). Using a basic understanding of the features which define these river microhabitat units, the river can be divided into distinctive pool, riffle, run sequences.

Data from historic and current riverbed and water surface elevations were used to create lateral and longitudinal transects of the river. This study uses only the data from the longitudinal transects. Using water depth, bed morphology, and a visual assessment of sequential river patterns, both current and pre-impoundment river conditions were distinguished as either pool or riffle/run areas. Due to the low resolution of detectable differences from this visual assessment, riffles and runs were indistinguishable. Habitat features derived from these profiles were used in determining the final spawning habitat under Method II. Additional information on data processing for channel morphology and river substrate can be found in Appendices A3 through A6.

Preliminary Velocity Data

Velocity data is important in classifying suitable spawning habitat, though it is currently not readily available for appropriate discharge conditions. Because of the importance of velocity as a feature of habitat suitability, this paper includes some preliminary velocity information from a two-dimensional hydrodynamic model. The conditions represented by the model in this study are for a discharge of 177 kcfs, which differs from the discharge conditions represented for both current (50 kcfs) and pre-impoundment (50-100 kcfs) conditions. Further work will be necessary to accurately model appropriate discharge conditions and water surface elevations.

The velocity data was classified as: areas with velocities less than the minimum suitability criteria (< .4 meters per second), areas meeting suitability criteria (values between .4 and 2 meters per second), or areas with velocities greater than the maximimum suitability criteria (> 2 meters per second). These data are strictly preliminary and have not been field verified. Additional information on the hydraulic model used is included in Appendix A7.

Data Analysis

GIS coverages were created for water depth, slope, aspect, and substrate for both current and pre-impoundment conditions. All analysis, data conversion, and computer work was completed using ArcInfo 7.1.2, ERDAS Imagine 8.0 or ArcView 3.0. Summary statistics were calculated on all coverages, and caculations were done to create additional surfaces. Longitudinal and lateral transects of water surface elevation and bed elevations were created using 3D Analyst in ArcView to assess riverbed changes. Finally, fall chinook spawning habitat criteria were determined from available literature, and the relative area of habitat meeting the spawning criteria was determined from the GIS coverages for both current and historic river conditions (Figure 4).

The criteria considered suitable for fall chinook spawning is a water depth of 0.3 to 9.0 meters, a slope of 0 to 5%, and substrates greater than 3 centimeters (Swan et.al 1988; Swan 1989; Connor et. al 1994; Geist 1998). Though this diameter of substrate is less than the reported range (in the Hanford Reach), limitations in scale and resolution of the substrate data categories made it necessary to use 3 centimeters as the lower level. All fines - clay, sand, sand/clay, sand/gravel, gravel/sand - are categorized as a failing substrate category (< 3 cm in diameter), and all categories larger than these - gravel,

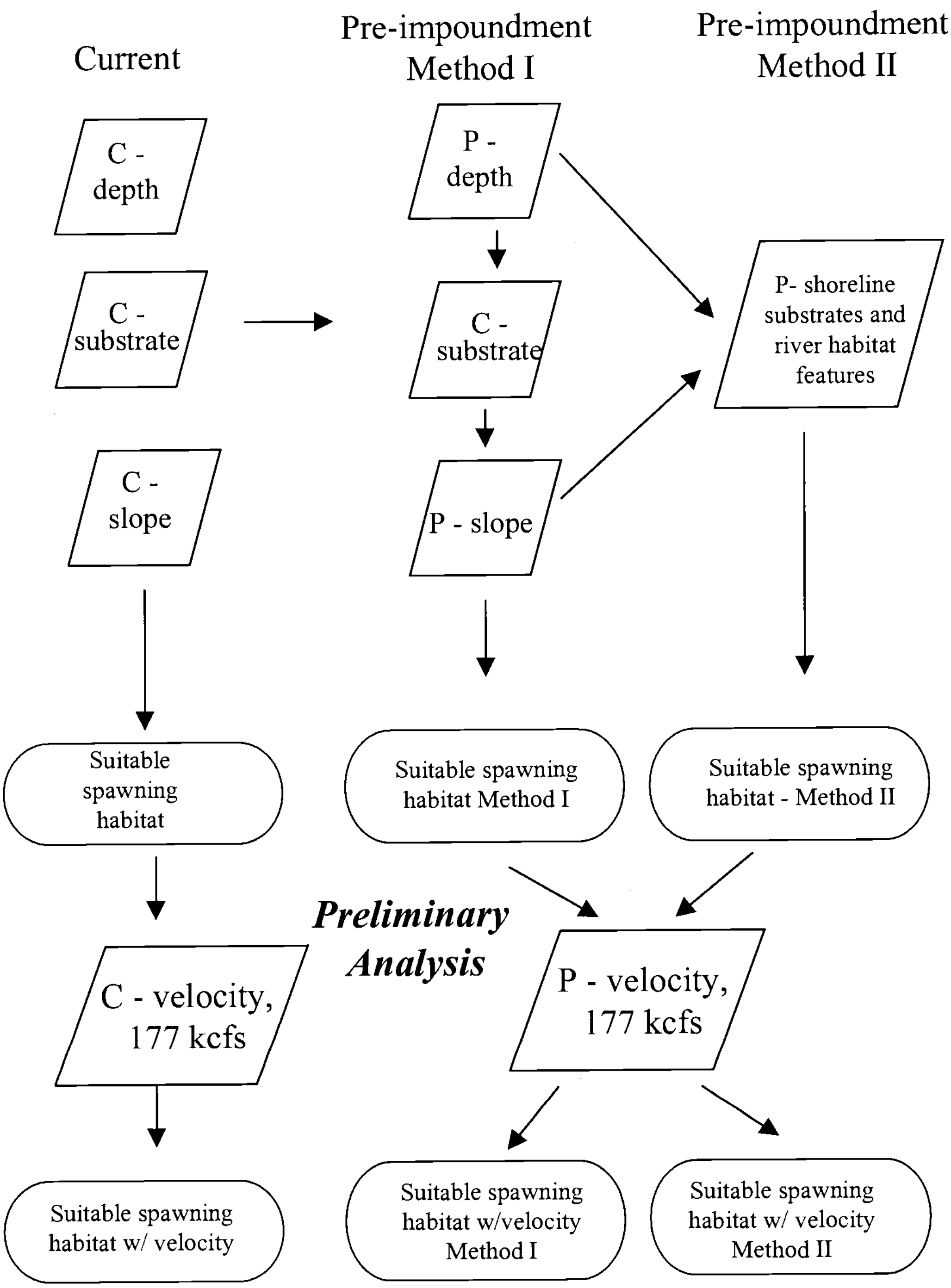


Figure 4. Flowchart of data sources and analysis

boulder/cobble, cobble, cobble/boulder, cobble/gravel, gravel/cobble - are considered suitable.

Limitations in substrate data for pre-impoundment conditions made it necessary to employ two techniques for the final analysis. Method I applies current substrate information to the extent of the pre-impoundment channel to designate areas which meet or fail to meet the substrate criteria. Current substrate distributions may not exactly represent historic distributions within the river channel. Areas of riverbeds that are exposed to high velocity flows typically maintain only the larger-grained sediments; we assumed this also to be the case in the Columbia River. In support of this assumption, the highest prevalence of substrates greater than two centimeters in diameter were found in the main channel of the river - which is the entire extent of the historic channel. Fine-grained sediments typically settle in low velocity areas, and based on the shape of the historic channel, few areas within the boundaries of the study area would have been low velocity, backwater areas.

Method II uses riffle locations to specify areas of the river which meet channel morphology requirements for spawning. Riffle locations were determined using longitudinal profiles of the riverbed and water surface. This method was employed to investigate how large-scale river morphology could affect the distribution of suitable spawning habitat patches in the river.

Preliminary Analysis of Spawning Habitat including Velocity Data

As part of a preliminary analysis for a future study, the classified velocity information described previously was combined with the results from Methods I and II for current and pre-impoundment conditions. General statistics were calculated for all three data sets. Overall distribution of suitable spawning areas were assessed, with consideration for the limitations in the data set resulting from the differing discharge conditions represented in the velocity data. Data from the model was not available for the area immediately downstream of McNary Dam, and for some shoreline areas due to gaps in the model. Consequently, the preliminary analysis of suitable spawning areas including velocity for both current and pre-impoundment condition uses a wetted area which is slightly smaller than that of the original coverages assessing suitable spawning areas for the other three features.

Results

Final results on topography, water depth comparisons, and spawning habitat for the two analysis methods are included in this section. All results and graphics resulting from intermediate analysis steps are included in Appendices B1 through B6, and Figures B through B .

Topographic Changes

The pre-impoundment river width ranged from 0.3 to 0.9 kilometers across. The currently submerged "Blalock Island" was 2298 hectares in size and located between RM

268 and RM 276 and split the original channel in two (Figure 5). The main channel, or thalweg, was located to the south of this island. The eastern section of Blalock Island was composed of a series of basalt/bedrock islands, and the north shore of the large island was a mix of bedrock and small, sandy shoals. The island was composed of sand dunes with sparse vegetation. A series of small islands were located in the upper end of the study area near Umatilla. Three major rapids occurred in this section of the river. Canoe Encampment Rapids were located at RM 261 and were approximately one mile long. Devil's Bend Rapids were located at RM 285, and Umatilla Rapids were located at RM 290. The Umatilla Rapids were two miles in length and were shallow enough to be treacherous for boat passage in high water and impassable during low water conditions. A channel was blasted through this shallow reef in 1918 (Lyman, 1918).

Presently, the east end of the study area is distinguished by a large island, Crow Butte, which was created by the reservoir (Figure 5). The river widens near the historic location of Blalock Island to a width of 4.4 kilometers. The channel shape reflects the partial submergence of Blalock Island. The small islands here are representative of the extant high elevation dunes which were originally part of Blalock Island and are above the inundation water level. Presently, these areas are composed of fine sediments, sand, and some exposed bedrock basalt areas. Vegetation on the islands is typical of the sage steppe biotic community typical of the shores of the eastern Columbia River Basin, and is comprised of sagebrush (*Artemisia* sp.) and other brushy vegetation, with some native grasses and willows (Shawn Steinmetz, pers. comm.). There are a number of small gravel and sand-covered islands with sparse vegetation in the current channel.

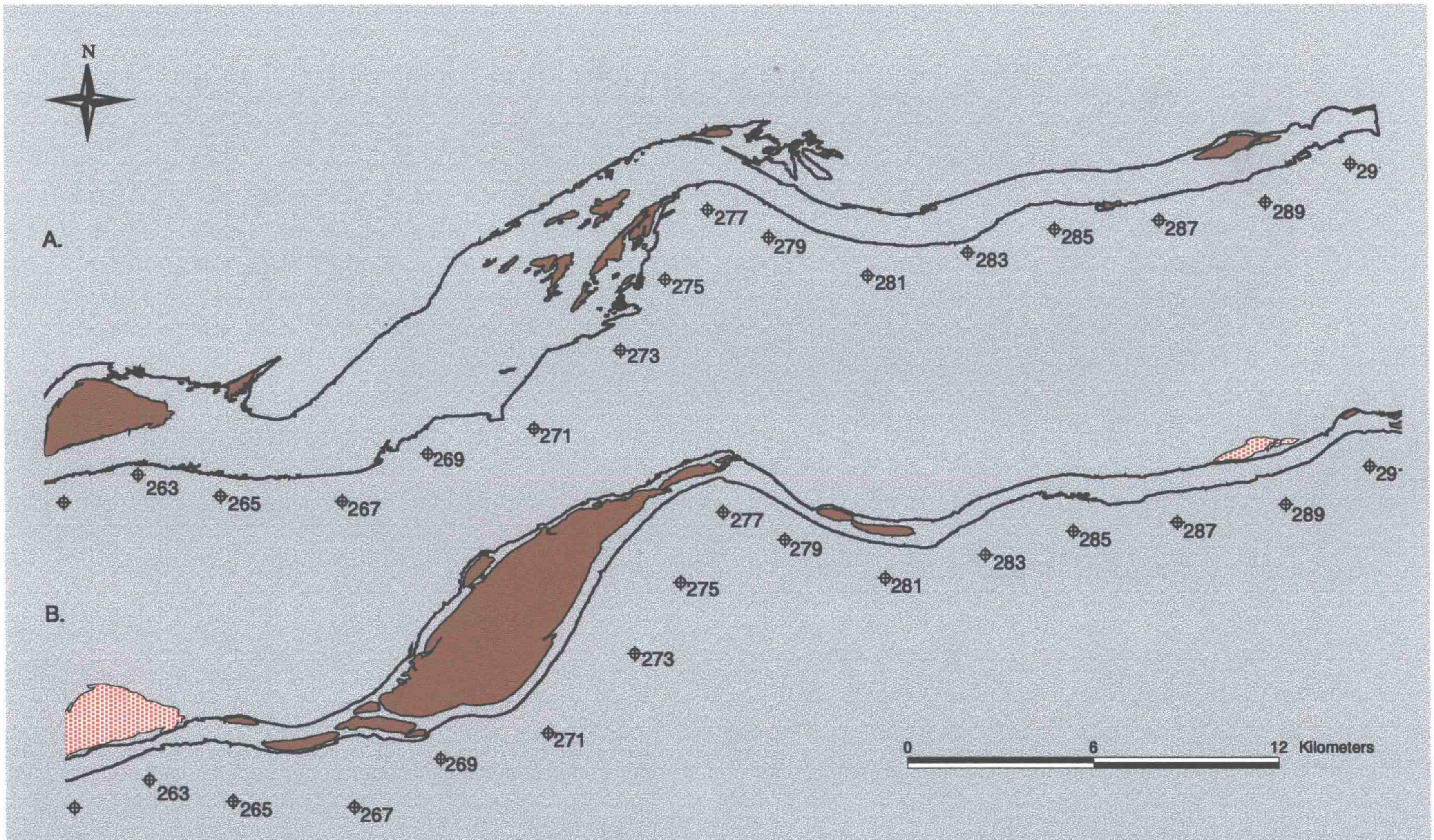


Figure 5. Channel boundaries of the current (A.) and pre-impoundment (B.) river channels. Islands are indicated in brown, and the red islands located on the pre-impoundment map did not exist but are presented for reference to current channel.

Hydrography

Historically, the water depths for this discharge ranged from 0 to 32 meters, and 67% of the wetted area was under less than 4.5 meters of water (Figure 6a, 6b). The main channel had a number of distinct pools, though most were relatively shallow. The main channel was characterized by water less than 4.5 meters deep, and most pools ranged from 4.5 to 24.5 meters deep. There were some distinctively deeper pools about 1.6 kilometers in length at RM 263, RM279, and RM 291 which were deeper than the other pools in this stretch of river. The most frequent category of water depths was for depths between 1.5 and 4.5 meters (41% of the total wetted area) of water, and depths from 0.3 to 9.0 meters comprised 90% of the 2640 hectare river channel. A histogram of the data indicates the values have a normal distribution with a peak at depths between 1.5 to 4.5 meters (Figure 7).

Current depths range from 0 to 36 meters, with 35% of the wetted area of the river under less than 4.5 meters of water (Figure 8a, 8b). Areas under 1.5 meters of water are located primarily in the lateral regions of the river, which were inundated when the river was originally impounded. The highest depth categories are shared between areas under 1.5 to 4.5 meters (23%), 4.5 - 9.0 (21%), and 9.0 - 15 m (19%). Depths from 0.3 to 9.0 meters comprised 54% of the 9561 hectare river channel (Figure 7). A histogram of the data indicates that the values have an irregular distribution with no true peak in data values. The original river channel is now the main channel of the river, although the mean depth has doubled in many places.

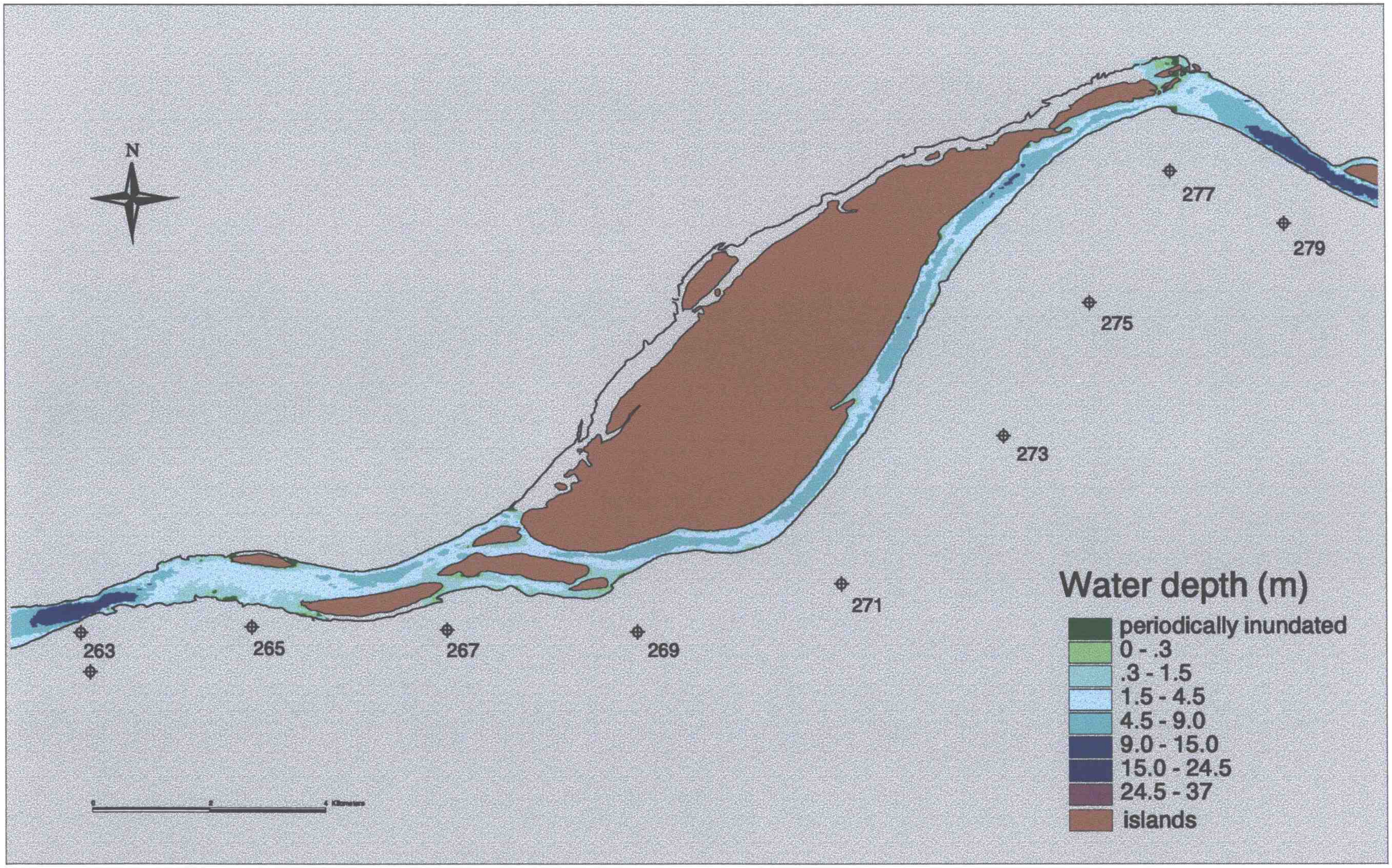
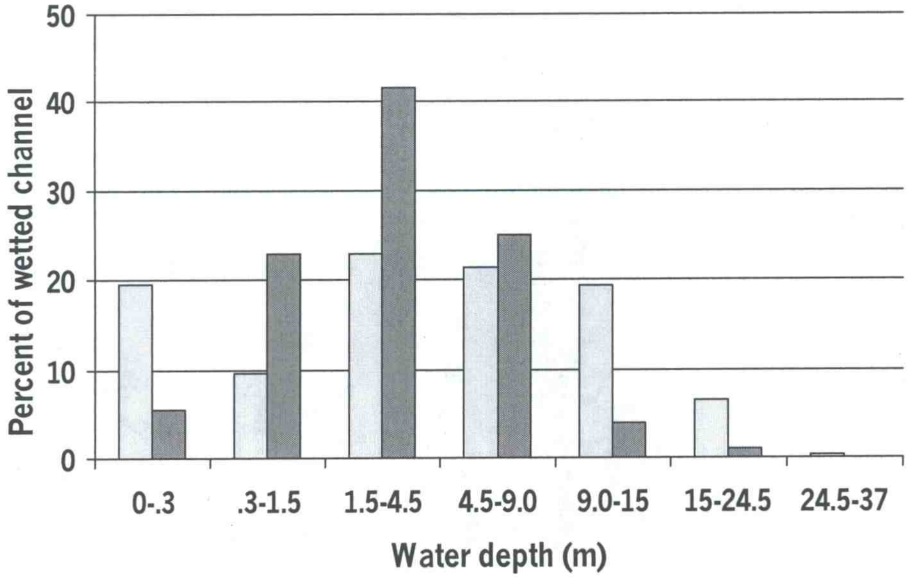


Figure 6b. Depth of river channel for pre-impoundment river conditions with a (regular discharge). This section represents the downstream half of the study area, river mile 261 through 277.

a.



b.

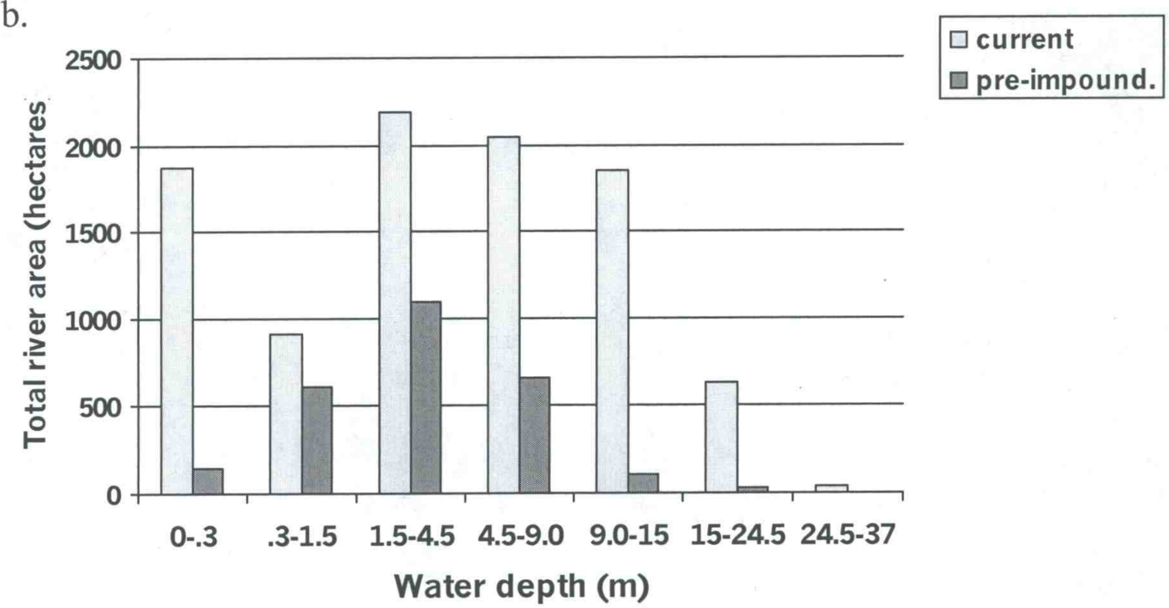


Figure 7. Distribution of water depth for current and pre-impoundment river conditions by percent (a.) and total area (b.). The total wetted area included in the study area is 9561.1 hectares for current conditions and 2639.9 for pre-impoundment conditions. Depth values for current conditions represent a discharge of 50 kcfs at both John Day and McNary Dams. Depth values for historic river conditions represent the mean low water plane, corresponding to a discharge between 50 and 100 kcfs.

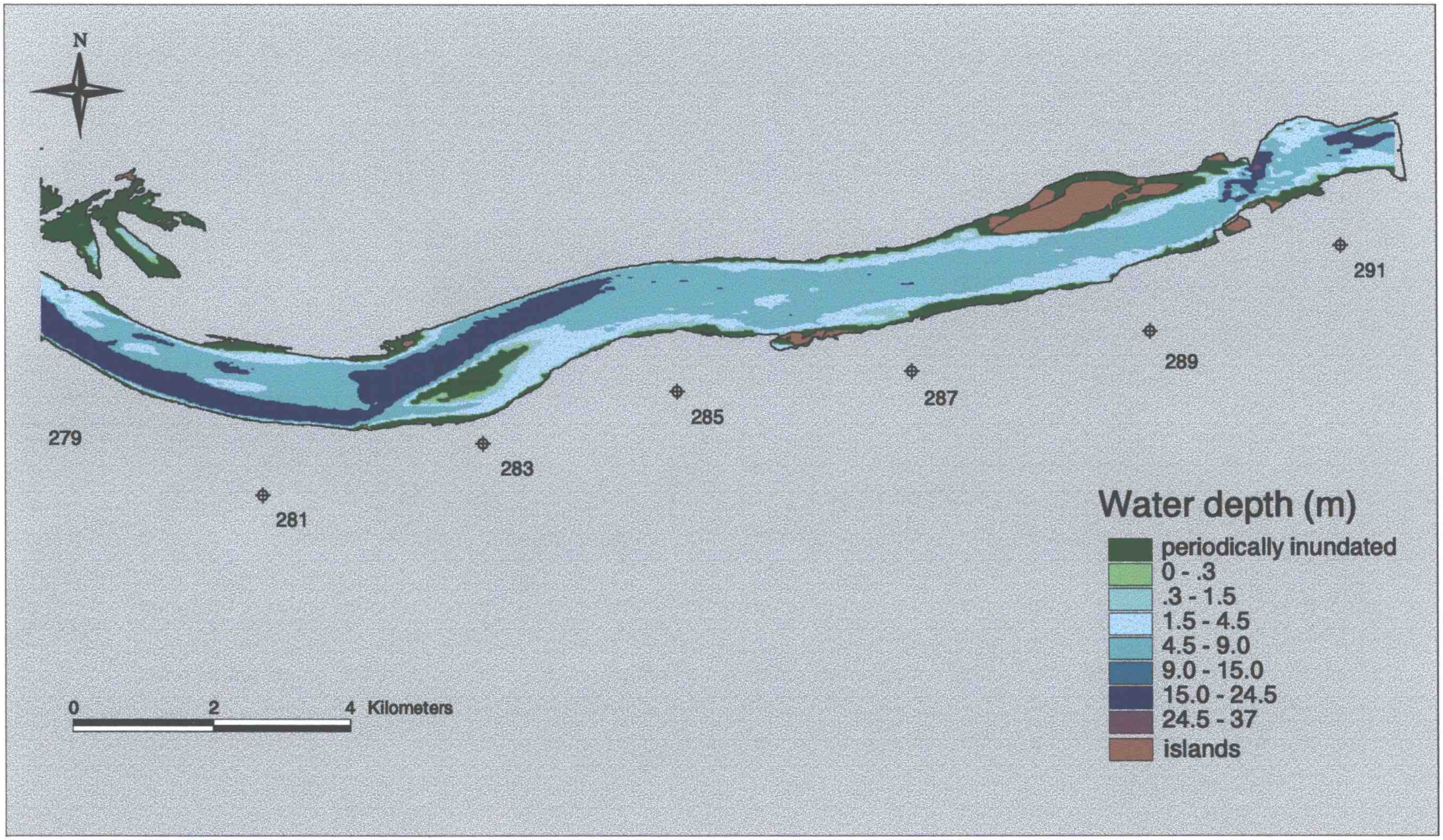


Figure 8a. Depth of river channel for current river conditions with a discharge of 50 kcfs. This section represents the upstream half of the study area, river mile 277 through 292.

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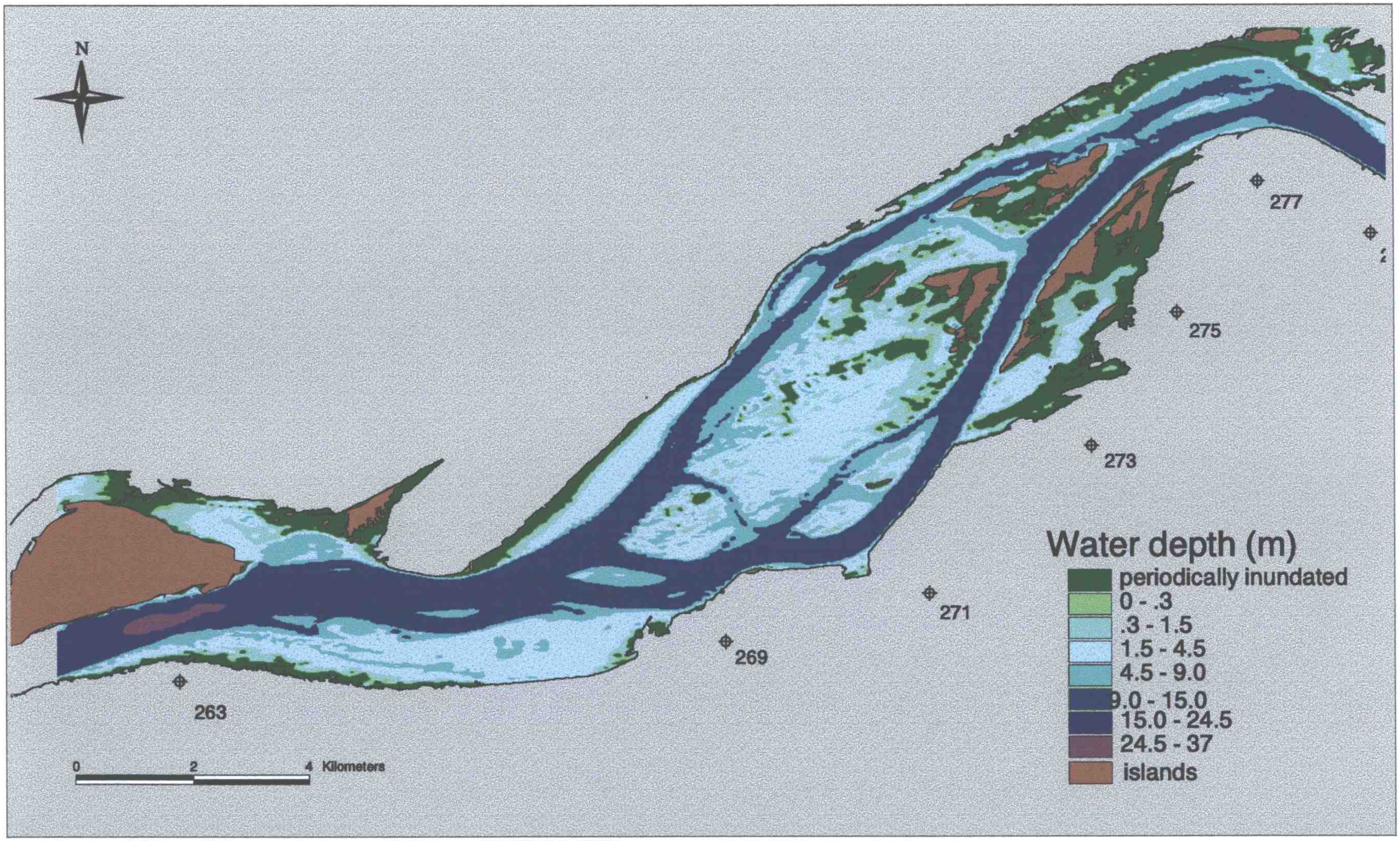

Figure 8b. Depth of river channel for current river conditions with a discharge of 50 kcfs. This section represents the downstream half of the study area, river mile 261 through 277.

The thalweg is typically deeper in the lower section of the study area than the upper section because of a backwater effect (Figure 8a). As previously mentioned, this effect causes more pooling in the lower section of the reservoir and the downstream section of the study area. The main channel in the lower half of the study area ranges from approximately 9 to 24.5 meters deep, while the upper half of the area ranges between 4.5 to 9 meters in depth. The increase in lateral dimension of the river channel has resulted in the creation of more areas under 1.5 meters of water. Most of the wetted area is evenly distributed among depths less than 25 meters.

Habitat Features and Bed Morphology

A longitudinal profiles of the water surface and riverbed gives an indication of the periodicity of the river features for both pre and post-impoundment conditions (Figure 9). For pre-impoundment conditions, the largest pools are found near RM 263, 279, and 291, and range in depth from 9 to 24 meters (Figure 10). There were a series of seven smaller pools throughout the stretch of the river, ranging in depth from 4.5 to 9 meters in depth. There were also a series of 8 riffles between the pools, commonly ranging from 1.5 to 4.5 meters deep.

The large-scale features in the current channel are more difficult to characterize (Figure 10). The bed shape is similar to the old channel, but the water depth has increased to cause most of the areas downstream from RM 284 to be classified as one long pool ranging from 9 to 24.5 meters deep. Areas which were previously characterized as riffles

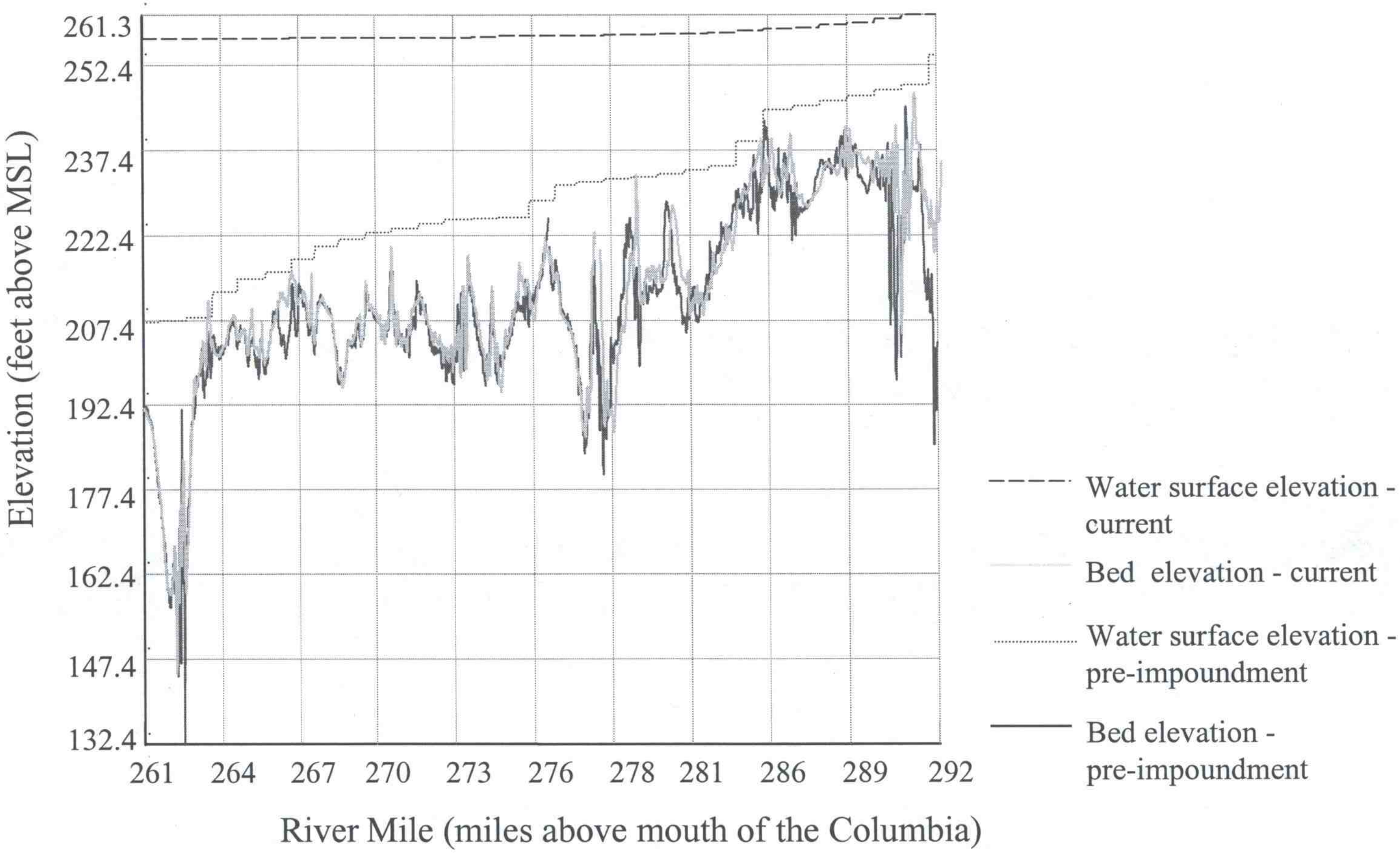

Figure 9. Longitudinal profile of the bed and water surface elevations for present and pre-impoundment channels. Profile lines are derived from elevation surface and represent depth at channel thalweg.

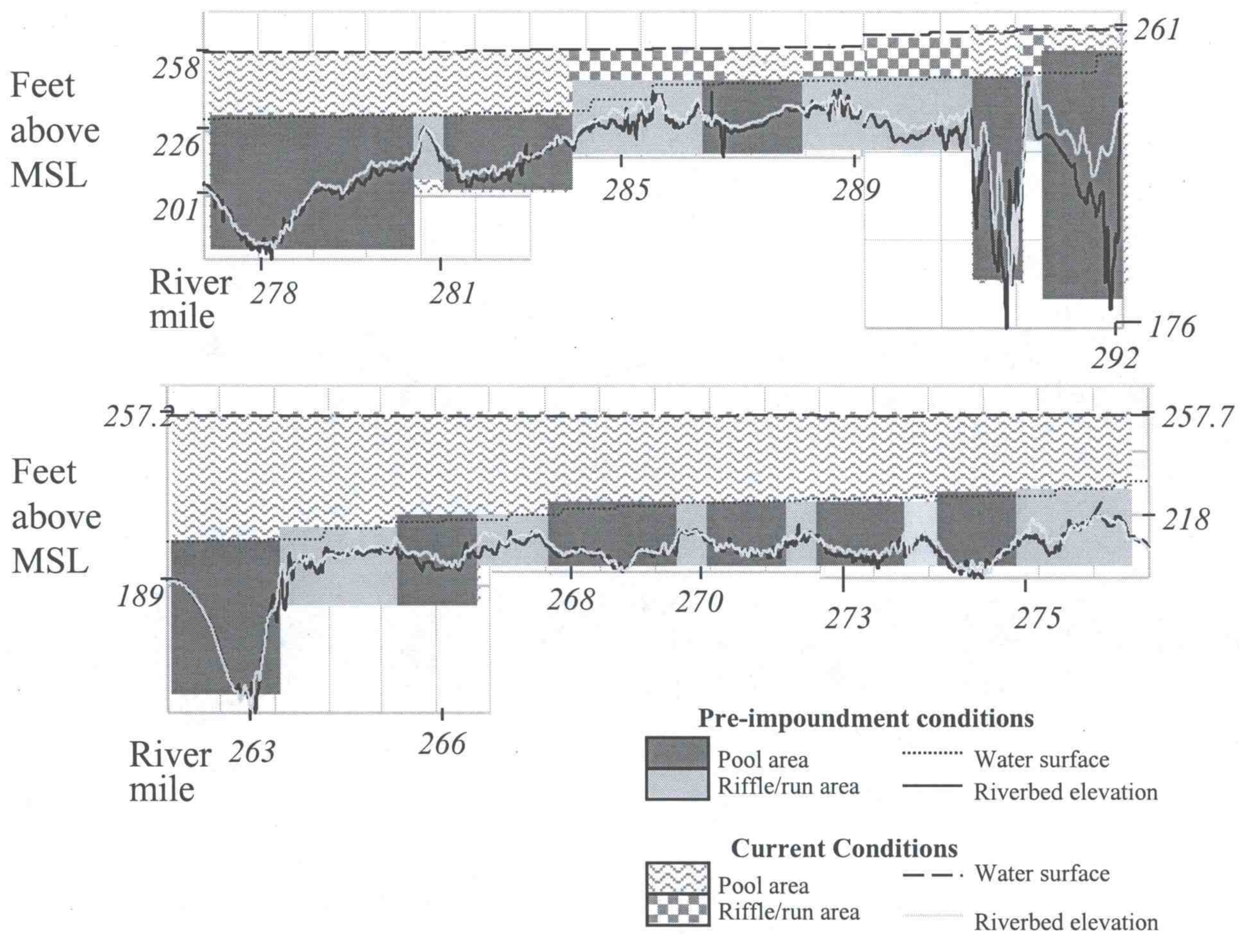

Figure 10. Longitudinal profile of current and pre-impoundment water and bed elevations with associated river habitat feature. The river was characterized as either a pool or riffle/run based on bed shape and water depth.

are now submerged under greater than 9 meters of water and can no longer be described as riffles. The peripheral areas in this lower section are difficult to delineate without additional velocity information. Based on the sediment distribution and water depth in these areas, they are shallow backwater areas little influenced by instream flows. There are three small distinct pools with depths greater than 15 meters upstream of RM 284 for current river conditions

Spawning Habitat

By using criteria for depth, slope, and substrates for current river conditions, under a discharge of 50 KCFS, it can be determined that the total area meeting spawning requirements is 1550 hectares or 16% of the total wetted channel. A total of 50% (4815 hectares) of the wetted area does not meet depth and slope criteria; and of the 50% that meet depth and slope requirements, 33% (3177 hectares) do not meet substrate requirements (Figure 11, Figure 12).

Using criteria for depth, slope, and Method I to characterize historic substrates, the total area meeting spawning requirements for pre-impoundment conditions is 1879 hectares, or 71% of the total wetted channel (Figure 13). A total of 16% , 429 hectares, of the wetted area does not meet depth and slope criteria, and of the 84% area meeting depth and slope requirements, 13% or 331 hectares do not meet substrate requirements for Method I (Figure 11).

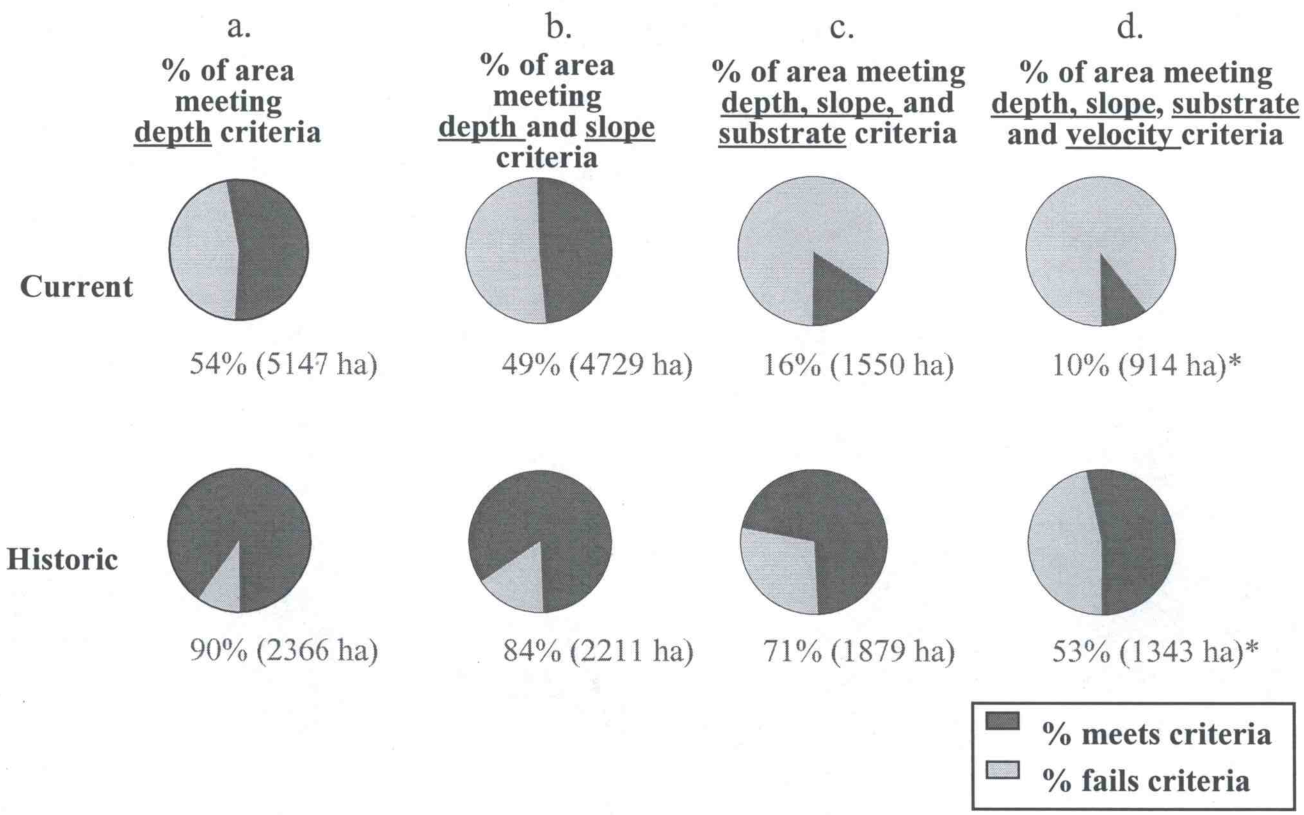

Figure 11. Habitat limitation for each step in the analysis. Data represents inclusion of limitations of the previous habitat characteristic for steps (a) through (d) in the analysis. The wetted area used in the analysis for pre-impoundment conditions is 2639 hectares, while the total wetted perimeter of the study area for current conditions is 9561. Inclusion of velocity as the fourth criterion is strictly preliminary; total wetted area included in step (d) is slightly smaller than for steps (a) through (c.) because of limitations in the extent of the velocity data. Calculations in step (d) are based on a total wetted area of 8782 hectares for current conditions and 2517 hectares for pre-impoundment conditions.*

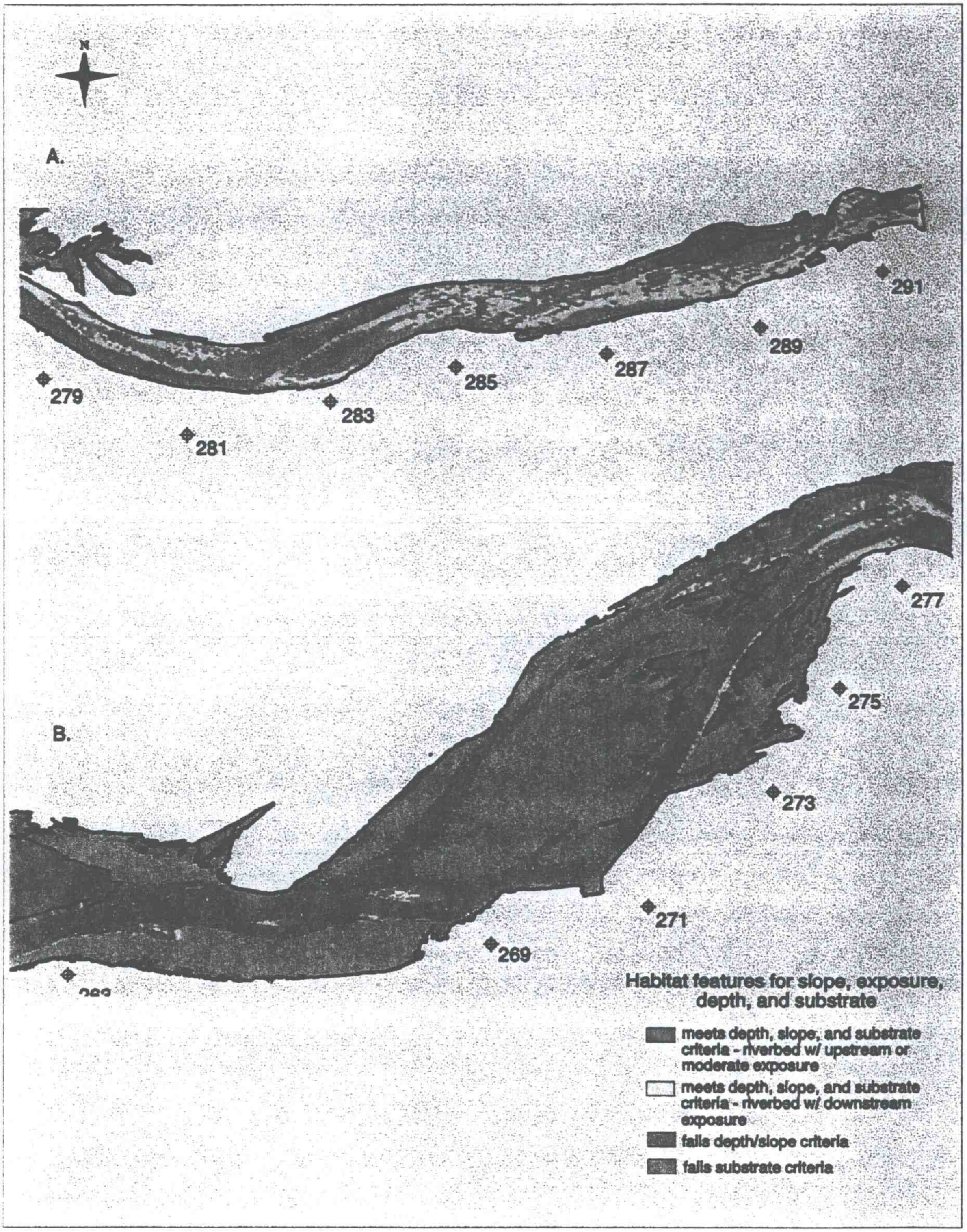

Figure 12. Distribution of suitable spawning areas for fall chinook salmon for current conditions which meet depth, slope, and substrate criteria. Red/pink represent suitable areas - see legend. Map section A represents upstream segment, from RM 278 - 292, and section B is the downstream segment from 263 - 278.

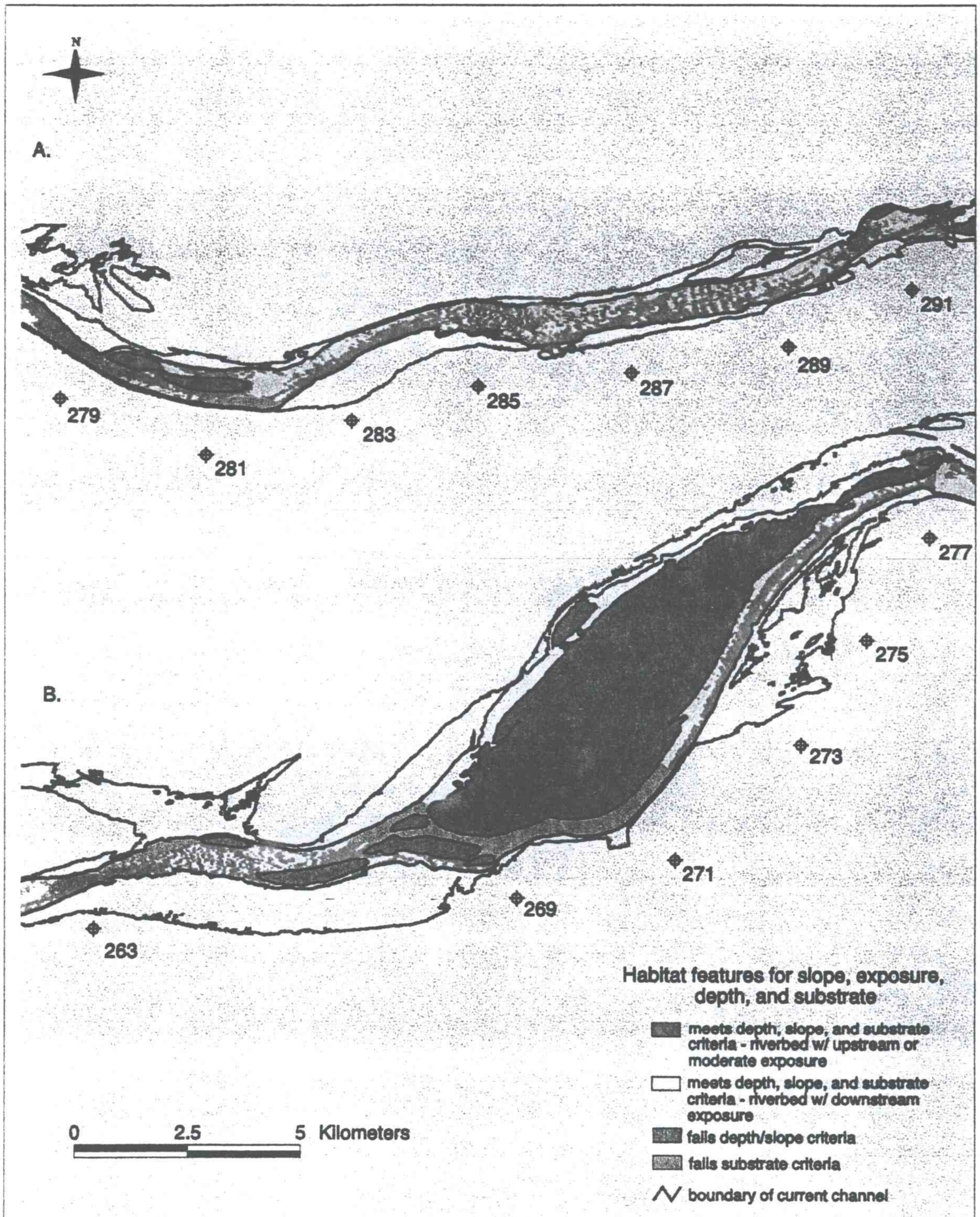

Figure 13. Distribution of suitable spawning areas for fall chinook salmon using Method I for pre-impoundment conditions. Method I uses current substrate information to determine historic submerged substrates. Red/pink represent suitable areas - see legend. Map section A represents upstream segment, from RM 278 - 292, and section B is the downstream segment from 263 - 278.

Using criteria for depth, slope, under Method II, the amount of pre-impoundment channel spawning habitat characterized as riffle areas which meet depth and slope requirements was 1320 hectares, or 50% of the total wetted area (Figure 14). Areas which are characterized as pools, but meet spawning depth and slope requirements are 884 hectares, or 34% of the total wetted area. Ten percent of the total wetted area which does not meet either depth or slope requirements are found in pool areas, and 6% of the remaining areas which fail depth or slope requirements area found in riffle areas.

Preliminary Analysis - Suitable Spawning Areas Including Velocity

Using criteria for depth, slope, substrates and velocity for current river conditions, under a discharge of 50 kcfs for depth and a discharge of 177 kcfs for velocity, the total area meeting spawning requirements is 913 hectares or 10% of the total wetted channel. A total of 6% (513 hectares) of the wetted area meet depth and slope criteria, but fail to meet the minimum velocity requirements; the remaining 84% (7354 hectares) do not meet depth, slope, or substrate requirements (Figure 11, Figure 15). Most areas failing depth and substrate are located in the downstream half of the study area, and would also fail to meet the minimum velocity requirement based on Appendix B5. The total size of the wetted channel considered in this analysis is 8782 hectares, which is less than the area considered in the previous analysis (9561 hectares) because of the limited extent of the velocity data downstream of McNary Dam.

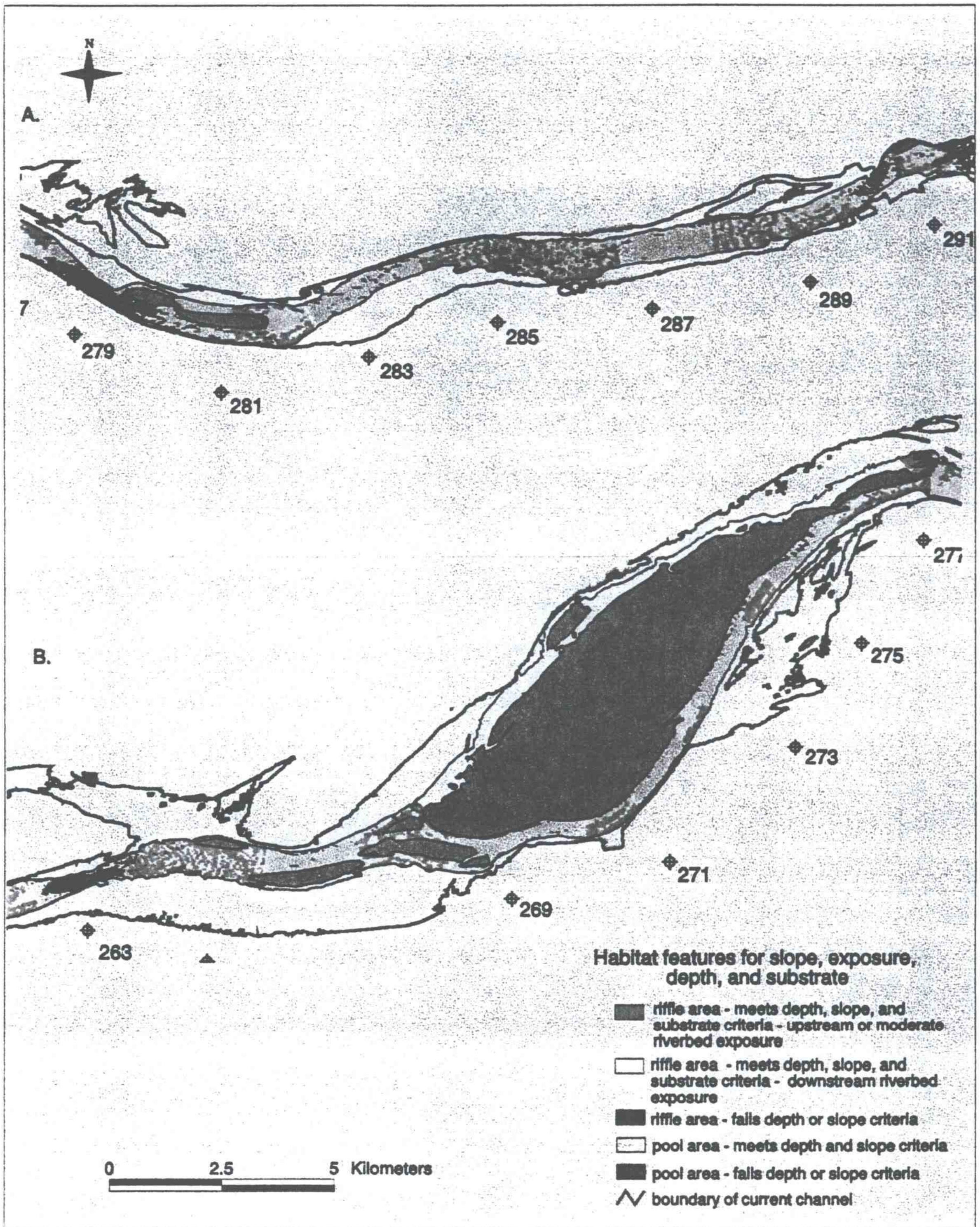

Figure 14. Distribution of suitable spawning areas for fall chinook salmon using Method II, pre-impoundment conditions meeting depth, slope, and river habitat criteria. Method II uses river reach classification to determine historic suitable areas. Red/pink represent suitable areas - see legend. Map section A represents upstream segment, from RM 278 - 292, and section B is the downstream segment from 263 - 278.

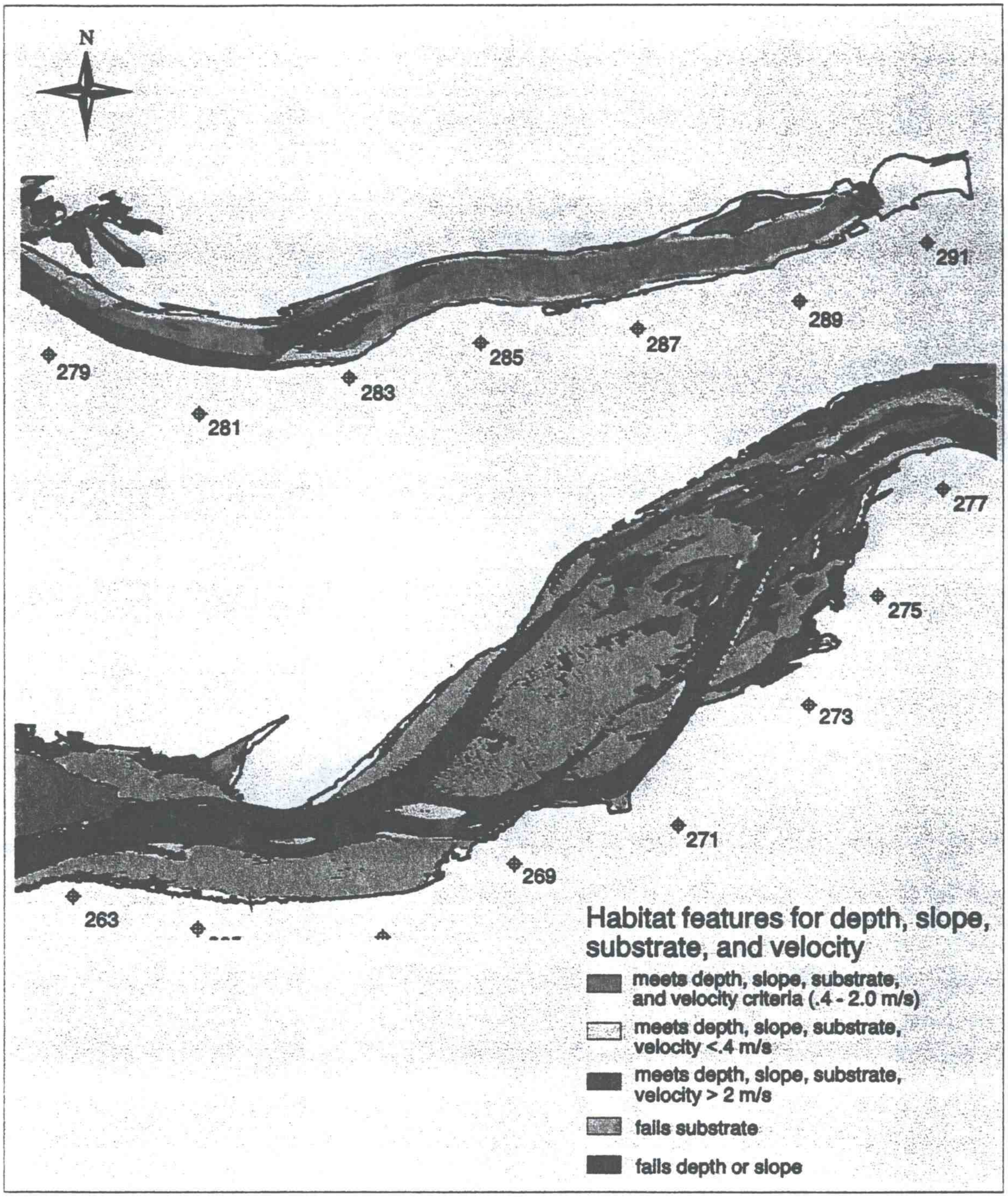

Figure 15. Distribution of suitable spawning areas for fall chinook for current channel conditions meeting depth, slope, substrate, and velocity criteria. Red indicates areas which meet requirement for all four features. Velocity data used in this analysis is preliminary and represents a discharge of 177 kcfs, which is higher than the 50 kcfs discharge that the depth values represent in this analysis. Areas which were previously classified as failing depth, slope, or substrate criteria were not tested for either meeting or failing velocity criteria. Only areas meeting these three features were tested for velocity suitability.

Using criteria for depth, slope, substrates and velocity for pre-impoundment conditions for Method I, the total area meeting spawning requirements is 1343 hectares or 53% of the total wetted channel (Figure 11, Figure 16). This represents a discharge of 50 to 100 kcfs for depth and177 kcfs for velocity. A total of 7% (181 hectares) of the wetted area meet depth and slope criteria, but fail to meet the minimum velocity requirements. Eleven percent (269 hectares) meet the depth, slope, and substrate requirements but exceed the maximum velocity criteria. Nine percent of the river meets depth, slope, velocity criteria but fails the substrate requirements. These areas are primarily located between RM 267 through RM 272 on the west end of Blalock Island, and the distribution of failing substrates is more likely related to the inundation of Balock Island, and the fact that substrate information for this area may incorrectly represent pre-impoundment conditions. The remaining 20% (510 hectares) do not meet depth, slope, or substrate requirements. The total size of the wetted channel considered in this analysis is 2517 hectares, which is less than the area considered in the previous analysis (2640 hectares) because of the limited extent of the velocity data downstream of McNary Dam.

Using criteria for depth, slope, velocity and Method II, the amount of pre-impoundment channel spawning habitat characterized as riffle/run areas which meet depth, slope, and velocity requirements comprise 909 hectares, or 36% of the total wetted area (Figure 17). Areas which are characterized as pools, but meet spawning depth, slope, and velocity requirements are 643 hectares, or 26% of the total wetted area. Five percent of the area characterized as riffle/run fail the minimum velocity suitability criteria, and 9% of the riffle/run areas exceed the maximum velocity criteria. Nine percent of areas are classified

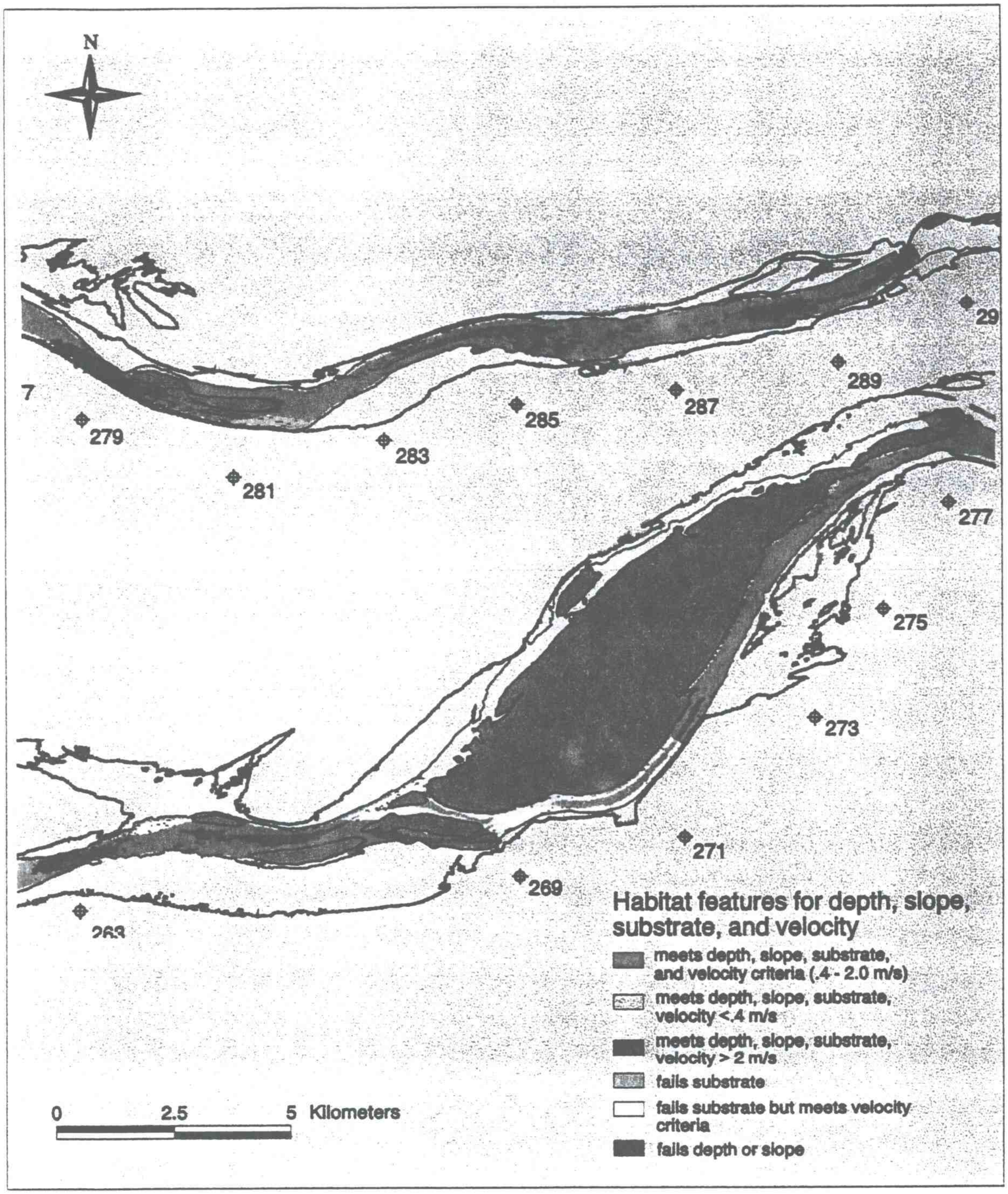

Figure 16. Distribution of suitable spawning areas for fall chinook for pre-impoundment conditions meeting depth, slope, substrate, and velocity criteria, derived from Method I. Due to the unsuitability of the current substrates to the historic channel in some areas, yellow indicates areas which questionably fail substrate criteria but meet velocity criteria. Areas which were previously classified as failing depth or slope criteria were not tested for either meeting or failing velocity criteria. Areas meeting depth and slope, criteria were tested for velocity suitability, as were areas which failed substrate criteria.

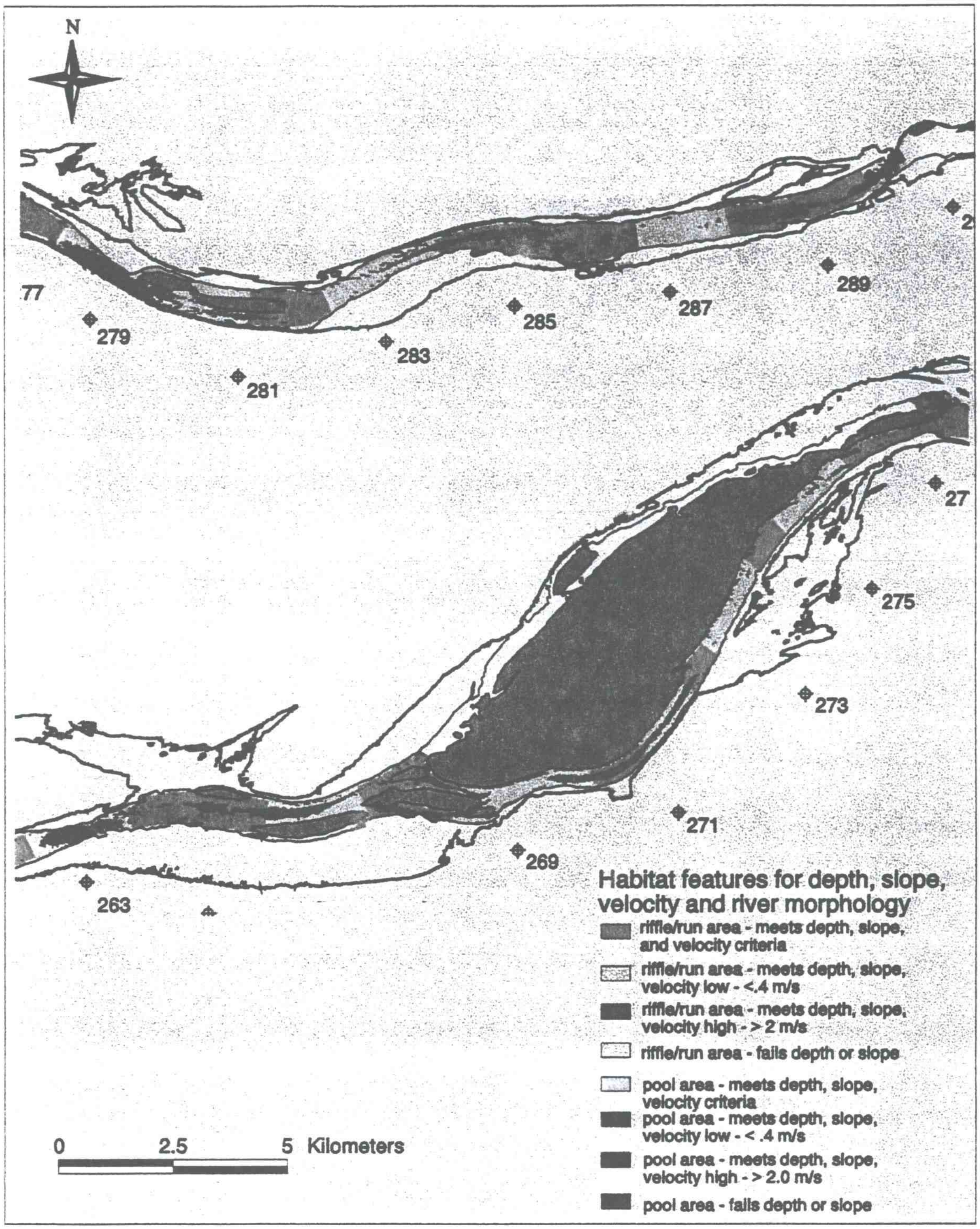

Figure 17. Distribution of suitable spawning areas for fall chinook for pre-impoundment conditions meeting depth, slope, substrate, and velocity criteria, derived from Method II. Method II uses river reach classification to determine suitable spawning areas based on morphology - riffle/run or pool. Velocity data represents the same conditions as in Method I.

as pools with velocities either failing or exceeding velocity criteria. The remaining 15% (388 hectares) of the wetted channel are riffles which fail the depth or slope criteria (140 hectares), or pools which fail the depth or slope criteria (248 hectares).

Analysis Limitations

Realistically, the depth for current conditions would increase if the river elevation and discharge was as high as that modeled in the velocity data. This effectively means that the preliminary results incorporating velocity represent a slight overestimation of suitable spawning areas, because velocities are higher than they would be if modeled for the low discharge represented by the depth measurements. If the depth measurements were adjusted to model water depths under the 177 kcfs discharge and combined with the 177 kcfs velocity data, more areas would exceed the maximum suitable water depth, which would mean that a smaller area would meet spawning suitability requirements.

Limitations in substrate information for both pre-impoundment and impounded conditions are related to the low density of sampling points which determined substrate types in the current river, and the necessity to apply current information to historic river conditions. This may have resulted in the underestimation of some suitable substrate areas under pre-impoundment conditions.

Limitations to the pre-impoundment data incorporating velocity data are in the slight overestimation of low velocity areas, because of errors in developing the historic shoreline boundaries, and the fact that the water extends higher on the banks of the river because of the higher discharge represented by the velocity model. Water depth would be slightly deeper than that represented in this study under a discharge of 177 kcfs rather than 50 to 100 kcfs, but based on the location of high water marks, this would not impact the distribution of areas meeting depth suitability criteria. The amount of area exceeding the maximum velocity suitability value would decrease with a discharge lower than 177 kcfs, which would effectively increase the amount of area meeting velocity criteria. The preliminary analysis of suitable spawning areas for current conditions for methods I and II represent a slight underestimation of suitable areas for these reasons.

Discussion

The river was historically typified by a complex channel pattern and features with shallow water and has changed to one with many deep-water areas, and lower channel sinuousity and complexity. These changes in river morphology have decreased the available suitable spawning habitat in this upper section of John Day Reservoir. It is unclear how well a river drawdown would replicate the historic channel conditions modeled in this study. The primary present limiting factor to suitable spawning areas is water depth, which would be minimized in the event of a drawdown, though it is unclear how substrate redistribution might impact suitable areas in a drawdown.

Limitations to suitable spawning areas based on substrate are primarily concentrated in the lateral areas inundated after the completion of John Day Dam. Consequently, most areas meeting substrate requirements for present conditions are found in the main channel of the river. These areas typically fail the depth criteria for spawning, especially in the downstream half of the study area. In the pre-impoundment channel, no outstanding limiting feature was found.

The primary differences between present and pre-impoundment conditions are found in the lower half of the study area, RM 261 through RM 279. These differences are related to backwater effect, which was discussed previously. The least amount of suitable habitat is found for present conditions in this lower stretch. As indicated in the preliminary analysis section, preliminary velocity data was used to predict areas meeting depth, slope, substrate, and velocity criteria. The low gradient waters of this section fail the velocity criteria, at least under these discharge conditions. The only area with velocities exceeding maximum criteria for present conditions are immediately downstream of McNary Dam. The upper river between RM 282 and 292 meets the necessary criteria for the four habitat features for most of the channel width during present conditions, because of the riverine conditions resulting from the decrease of backwater effect and the proximity to McNary Dam, effecting velocity and substrate size.

Pre-impoundment conditions are represented by three different scenarios. The one that is most comparable to the method used to estimate current areas is Method I, which indicates the amount of suitable spawning area using current substrates to represent the historic substrate distribution. This method predicts the highest amount of suitable habitat including features of depth, slope, substrate, and preliminary velocity models. The primary limitation to suitable locations is a large patch of fine sediments in the channel near RM 271, and some high velocity areas throughout the channel. This patch of fine sediments may be a symptom of using the current substrate data to represent pre-impoundment conditions. An area comprised of fine sediments is located in the main channel immediately downstream from Blalock Island. This material probably came from Blalock Island and filled in the original bed materials when the river was inundated, but historically was not present. Suitable sites are distributed evenly throughout the entire stretch of the study area, with little difference between upstream and downstream sections.

Method II includes elements of habitat features which were not used in Method I or the technique used to model current conditions. Method II includes water depth, slope, and type of geomorphic habitat feature to determine suitability for spawning. Because riffle features are generally considered more suitable for spawning, areas which meet the three criteria and are located in a riffle are represented. Prelimary analysis also uses data derived from Method II and considers velocity and morphological feature along with depth and slope. The method used in this study for designating riffle/run and pool sequences was subjective, and based solely on riverbed morphology and water depth. A more objective method is available for identifying these habitat features, which are very important in characterizing the suitability of a river for salmon.

A calculation devised by Chow (1959) allows the assignment of habitat feature type (pool, riffle, run) by calculation of the Froud number (Fr). Froud number is the dimensionless velocity/depth ratio $Fr = V_m / \sqrt{(gY)}$, where V_m is the mean water column velocity, Y is water depth, and g the acceleration due to gravity (Jowett, 1993). Froud number has been used to objectively identify habitat types using a calculation including water velocity, depth, and the acceleration of gravity (Jowett, 1993; Yu and Peters, 1997). Preliminary analysis using Froud numbers for the pre-impoundment John Day Reservoir indicates that most of areas classified as riffles or runs using the longitudinal profile method described earlier meet the Fr requirement for riffles or runs (Rupp, unpublished data). The advantage of using a calculation is that calculations allow spatial intermediaries - that is, areas that are numerically between riffles and pools. This would better represent the true nature of the river, and this method will be used in further work on this project.

All estimates of suitable fall chinook spawning habitat for pre-impoundment conditions were greater than estimates of current habitat. Method I estimates the highest amount of pre-impoundment habitat, and Method II with velocity estimates the lowest. It was difficult to complete an analysis of habitat features (as in Method II) for current conditions because of limited quantitative information on classifying river habitats, and the depth and homogeneity of the channel. Preliminary analysis of the Fr number for current channel conditions indicates that the only areas which would classify as a riffle are within RM 289 through 292 downstream of McNary Dam. The remainder of the river in the study area is represented as a pool (Rupp, unpublished data).

It has been reported that to appropriately define habitat suitability models for salmon, it is necessary to include features such as water depth, velocity, substrate, lateral bed slope, bed scour, and small-scale geomorphic features of the river (Milhous 1979; Stalnaker 1979; Conner et al., 1994; Geist and Dauble, 1998; Geist 1998). The estimates of spawning habitat presented in this study have attempted to include as many of these predictive features as possible, considering the limitations of the historical information. It is important to consider that the distribution of possible habitat includes areas which meet certain criteria, but estimates do not include small-scale hydraulic features such as hyporheic flow. A study by Geist (1998) found that though water velocity and lateral bed slope appeared to be the most important variables in predicting redd sites in the Hanford Reach of the Columbia, the difference in smaller-scale hydraulic features between spawning sites indicated that there are other considerations in spawning site selection. The areas predicted in this study indicate the outer boundary of areas suitable for fall chinook spawning. These are not meant to predict historic redd locations. The interpretation scale of these results is more regional than site specific within the river; assessment is not intended to be used on an individual habitat cell basis.

Conclusions

The drawdown of the John Day Reservoir is being considered as an optional river modification to benefit Columbia River salmon. This reconstruction of the historic river does not address the hydraulic features which created the natural river channel. Natural flood events and seasonal water fluctuations created the historical river channel; a drawndown river may physically reside in the original channel, but the historic hydraulic character of the river will be missing. The unregulated river underwent seasonal and yearly fluctuations in water levels which typically do not occur under current conditions. These conditions resulted in a diversity of aquatic habitat that is no longer available in the current system.

In the "Return to the River" concept, it is important to understand what kind of river it is possible to regain. The river represented in this study portrays a snapshot in time, and does not depict a variety of discharges or the spatial variation in habitat which occurs over time under a natural flow regime. It can be used as a general measure of the important riverine features previously existing in the John Day Reservoir. The goal of a drawdown is to return the river to a condition more representative of the free- flowing river to improve habitat and migration of Columbia River salmon. This study approximates the distribution of fall chinook spawning areas in the mainstem Columbia River. More work is necessary to describe the features which are necessary for rearing and migration of fall chinook, spring, chinook, and other salmon in the Columbia River System.

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APPENDICES

Appendix A

Hydrographic Data – Appendix A1

The historic maps contain shoreline boundaries, water surface elevations, triangulation points, landmarks, latitude/longitude and state plane coordinate system tick marks, symbolization depicting shoreline sediment size, and point depth values (68,322 point measurements) throughout the river. The point depth measurements were collected for a series of transects approximately 110 to 120 meters apart. The distance between measurements within one transect ranges from 5 to 15 meters apart. The survey depth measurements are adjusted to a "low water plane", and map notation indicated that this corresponds to .3 ft. on a gage near Umatilla, Oregon. Information on this particular gage is currently unavailable, but based on hydrographs from both Priest Rapids and The Dalles from 1930 through 1940, the mean low water plane ranged from 50 to 100 kcfs (Grant County Public Utility District, 1979; USACOE, 1946). For the purposes of this study, it is assumed that the discharge and depth conditions represented by historic river were in this range.

The current hydrographic dataset are a series of 45,076 point measurements throughout the river. The point measurements are expressed in feet above mean sea level (MSL), so they represent bed elevations of the river rather than water depth. Elevations in this study are expressed in feet rather than meters above mean sea level to maintain standardization with USACOE units. The point data are in bathymetric transects, which were taken approximately 150 to 160 meters apart, with a sampling distance between elevation points ranging from 20 to 30 meters.

Processing of Hydrographic Data – Appendix A2

In order to create a continuous surface of bed elevations for the current channel, it was necessary to interpolate the data points. A spline interpolator was chosen as the best method of interpolation because it creates a smooth, continuous surface which passes exactly through the original data points. This type of interpolator , which is also referred to as thin plate interpolation, also ensures smooth first-derivative surfaces (ESRI, 1998). Because the slope and aspect values were both derived from interpolated surfaces, the continuity of first-derivative surfaces was essential. Derivative surfaces generated when using other interpolation techniques with these data (Inverse Distance Weighted and Trend) were inaccurate and unrepresentative of the phenomenon being modeled, so these techniques were not used.

Once a surface was created to represent the bed elevations, a series of backwater curves (graphs depicting water surface elevation at different locations in the reservoir) were used to create a continuous surface for the changing elevation of the water surface. The backwater curve changes, depending on the gradient of the river and discharge levels. There is a "backwater effect," which causes a relatively flat water surface in the lower half of the study area and more variability in the upper section of the study area. Water surfaces (ArcInfo grids) were created representing discharges of 50,000 cubic feet per second (50 kcfs) and 200,000 cubic feet per second (200 kcfs) for both the upstream dam, McNary, and the downstream dam, John Day. The water surfaces and bed elevation models were then substracted from each other to determine the actual depth values for current river conditions. The depth data represents the John Day Reservoir with a pool elevation of 257 feet MSL.

The historic survey data points were digitized from hardcopy maps, which resulted in an overall root mean square (RMS) error corresponding to errors on the ground ranging from 2.5 to 5.7 meters. A spline interpolator was also used to interpolate these data, creating a continuous surface of the water depth for the study area. In order to model differences in bed elevations due to changes in sediment distribution, it was necessary to convert the depth elevations to bed elevations in feet above MSL. The was done using a technique similar to that done with the current dataset. Using thalweg longitudinal transects included with the historical maps, a surface was created to represent the elevation of the water surface. The water depth grid was then subtracted from the water surface grid to create a surface representing bed elevations.

Aerial Photographs – Appendix A3

The available air photos were a series of 1:20,000 scale black and whites. The photographs were scanned at a resolution of 600 dots per inch (dpi), then converted to ArcInfo grids with a cell size of 37.2 meters^2 per cell. By use of a digitized outline of the river channel from the hardcopy maps, each photograph was georeferenced and rectified to correct photo distortion. The rectified photos were then mosaicked together, using the georeferenced ArcInfo grids. The orthophotos provided by the U. S Army Corps of Engineers required no processing.

Channel and Bed Morphology – Appendix A4

The general extent of the channel boundary for current conditions was determined from existing GIS (Geographic Information System) coverages of the study area which were created by Columbia River Research Laboratory (CRRL) personnel using NOAA charts, with updates from additional CRRL field research. The outline of the historic channel boundary was digitized from the fourteen War Department hydrographic survey maps and 1944 aerial photographs of the area, resulting in individual map RMS errors ranging from 0.2 to 1.4 meters on the ground (Appendix A3). Slope and aspect values were calculated from the bed elevation data (Appendix A4).

Calculation of Slope and Aspect Values – Appendix A5

The bed elevation information derived from the depth data for current and historic conditions was used to calculate the lateral slope of the riverbed. This calculation considers the slope, or maximum rate of change from each grid cell to the neighboring cell, and assigns this value to cells in a new grid. This was limited to small-scale areas of the river, 37.2 m^2 each, and did not represent the overall longitudinal slope of the study stretch. The bed elevation was also used to determine the direction of the slope, or aspect, of the riverbed. This calculation identifies the steepest down-slope direction from each cell to the neighboring cells, and assigns a number to each cell corresponding to the cardinal directions (ESRI, 1998). Bed aspect was used to help define exposure to river velocities. The aspect was thus defined as: upstream exposure - slope facing upstream (45° to 135°); indirect exposure - slope facing shorelines of river (0° to 45° and 135° to 180°); or downstream exposure - slope of the riverbed is facing downstream (180° to 360°).

Substrate – Appendix A6

Substrate information for current conditions was determined using existing GIS coverages of the study area, which were created by CRRL personnel from a series of substrate sampling points throughout the river. A series of polygons were created from these data to represent the predominant substrate types in the river, which were ordered into the following eleven classes: boulder/cobble, clay, cobble, cobble/boulder, cobble/gravel, gravel/cobble, gravel/sand, sand, sand/clay, sand/gravel, organics.

Pre-impoundment substrate information is limited to shorelines. The hardcopy maps contain a symbolic representation of the shoreline sediments and particle size and were digitized from these notations. Aerial photographs were used to help determine shoreline, island, and shallow water substrate type. The eight classes distinguished from the maps and photos are bedrock, bedrock/sand, boulders, cobble/gravel, gravel, sand, gravel/sand, gravel/cobble (Rosenfeld, pers. comm.). This allowed a limited assignment of substrates for the historic riverbed.

Velocity Model Background Information – Appendix A7

The model used to generate velocities for the current and pre-impoundment channels is "cdg2d", a depth averaged hydrodynamic model developed at the University of Alberta (Steffler , 1997). This model was chosen for compatibility reasons; the final results from this model will be shared with other federal agencies that have been using this model and found it to be sufficient. To represent historic conditions, a water surface elevation of 164 feet above MSL (at the John Day Dam site) was used to generate data for the entire length of the John Day Reservoir for a discharge of 177 kcfs. Current conditions were modeled using a water surface elevation at the John Day Dam site of 263 feet above MSL, and data was calculated for the length of the reservoir. Both discharge and the water surfaces are higher for current conditions than those represented in this study. Consequently, model data represents a slight overestimation of the amount of high velocity areas for both river conditions, though it still allows assessment of the overall hydraulic differences between current and pre-impoundment conditions

Appendix B

Water Levels – Appendix B1

The current water surface from McNary dam to Crow Butte varies less than 6.2 meters, though the pre-impoundment water surface varied approximately 18.6 meters in the same distance. The previous water surface was at 207.4 feet above MSL at RM 261, and the current water surface is 257.2 above MSL at the same location (Figure B1.1). The water

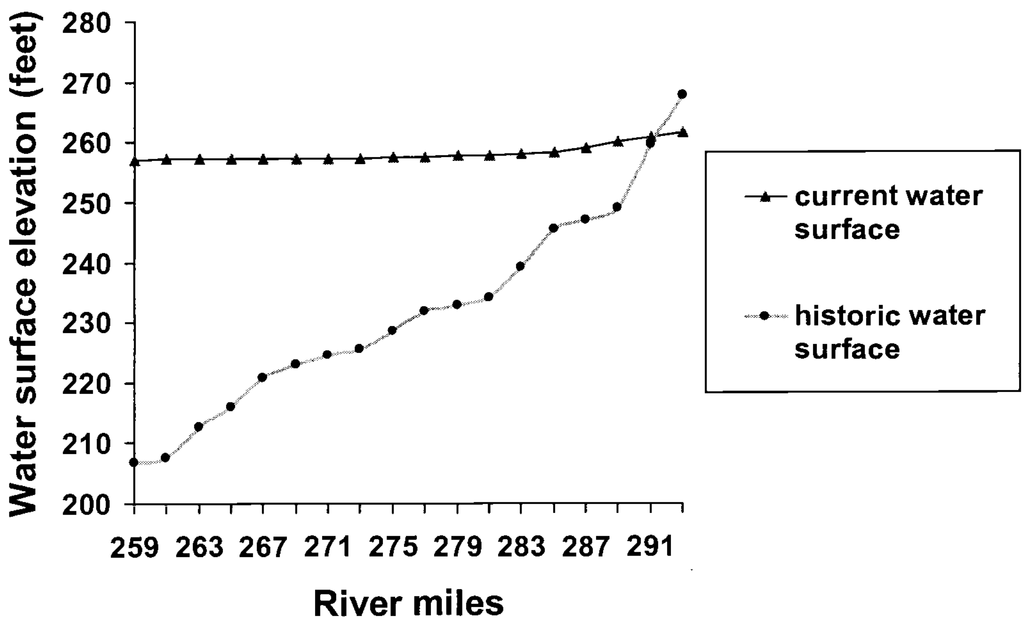

Figure B1.1. Difference in water surface gradient for current and pre-impoundment conditions. The study section begins at river mile 260; John Day Dam is located at river mile 216. Elevation is in feet above mean sea level. River miles are expressed as the distance from the mouth of the Columbia River.

surface for current conditions remains relatively constant from RM 261 through 287, and changes in the upper section of the study area from RM 287 upstream to the McNary Dam RM 292 (Figure 9). The lessening backwater effect near RM 287 is the reason for the shallower, faster moving water in the upper stretch. Higher discharges through McNary and John Day Dams result in a higher gradient for the water in this upper section, and a greater difference between upstream and downstream water elevations. The pre-impoundment river was reported to have had a gradient of .3 meters per mile for non-rapids areas and drop of .6 to 2.4 meters per mile for rapids (USACOE, 1951).

Riverbed Slope – Appendix B2

The amount of riverbed with slopes from 0 to 5 percent in the current channel is 8878.7 hectares (93% of total wetted channel) (Figure B2.1) and in the historic channel was 2444.8 hectares (93% of the wetted channel) (Figure B2.2). Most of the area in the pre-impoundment channel had slope values of 0 to 2 percent (68% of the total area), similar to the current channel (71% of total area). Patchy bed slope values make the location of major rapids at RM 261, 285 and 290 discernible from these maps, even without prior knowledge of their presence. Most of the high slope areas are located along the shoreline of the submerged islands or in sections with riffles or major rapids.

The riverbed common to both pre- and post-impoundment has undergone few changes, and the ratio of low to high slope areas is unchanged. The post-impoundment riverbed has the same slope values as the pre-impoundment channel. In the current channel, the

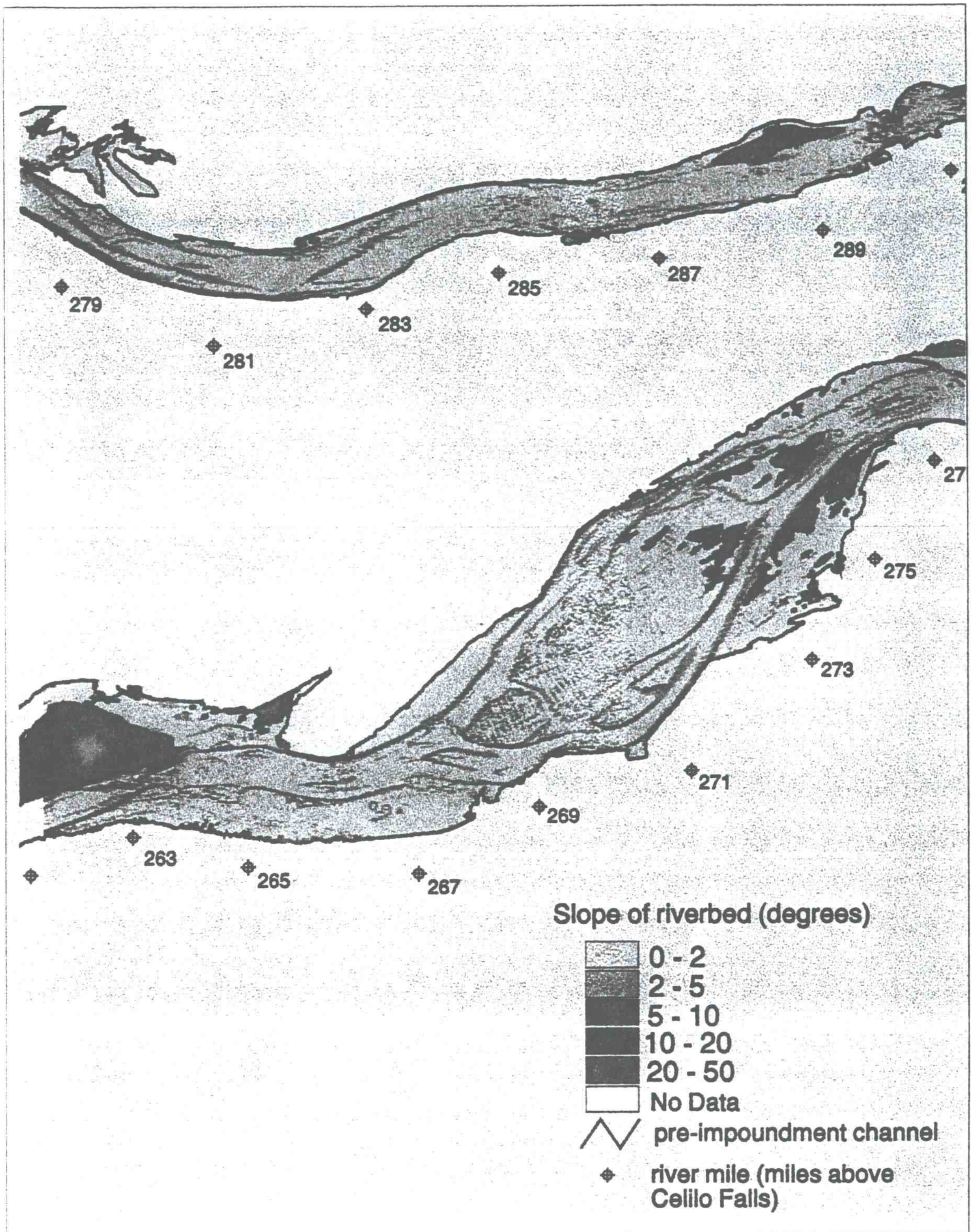

Figure B2.1. Riverbed slope for current channel conditions

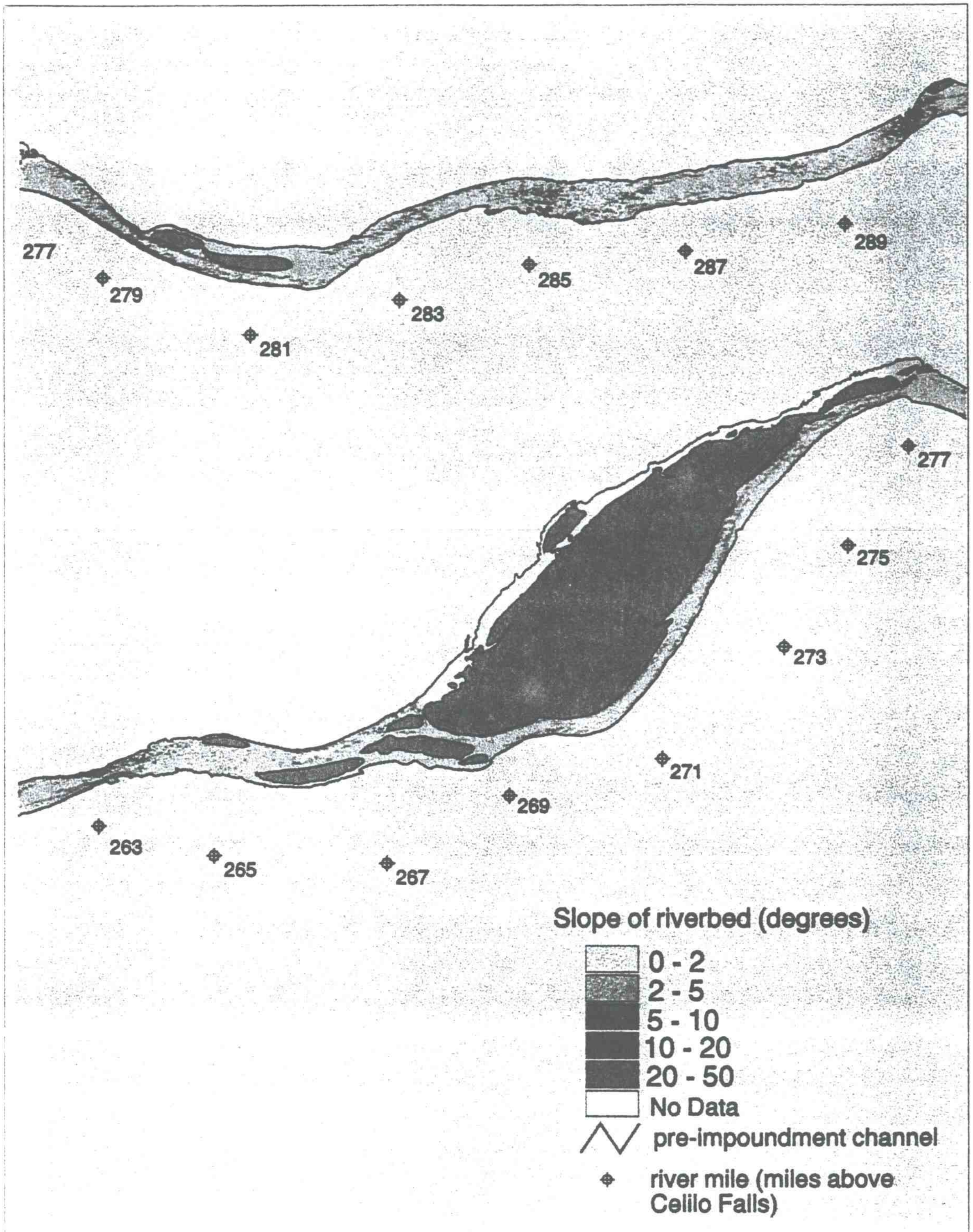

Figure B2.2. Riverbed slope for pre-impoundment channel conditions increase in high, >5%, and low, <5%, slope areas result from the lateral areas of the channel that were inundated. Areas greater than 5% are mainly the submerged pre-impoundment steep upper shorelines, and areas less than 5% slope were previously the flattened plateau of the original river bank. Current slope values in the upper pool show evidence of riverbed smoothing due to proximity to the upstream dam (McNary Dam) and dredging operations conducted in the early 1900s. The amount of high slope areas increased from 195 hectares to 682 hectares, and the low slope areas have increased from 2445 to 8879 hectares. The ratio of low to high slopes remains the same because of a proportional increase in high and low slope areas with inundation.

Depth and Slope Criteria – Appendix B3

The amount of area meeting both depth and slope criteria for pre-impoundment conditions is 2211 hectares, 84% of total area (Figure B3a,b). In the lower section of the study area, RM 261 through RM 277, the distribution of areas meeting depth and slope criteria is limited along shoreline areas. This is because of slopes greater than 5% and depths either greater than 9 meters or shallower than .3 meters, especially between RM 263 and RM 267. The upper section of the study area, RM 275 through 292, is limited mainly by a deep pool near RM 278, and high slope values found at Devil's Bend Rapids.

The amount of area meeting depth and slope criteria for current conditions at this discharge is 4729 hectares, or 49% of the total wetted area of the river (Figure B3a,b). The areas which meet depth and slope criteria in the lower section of the study area are

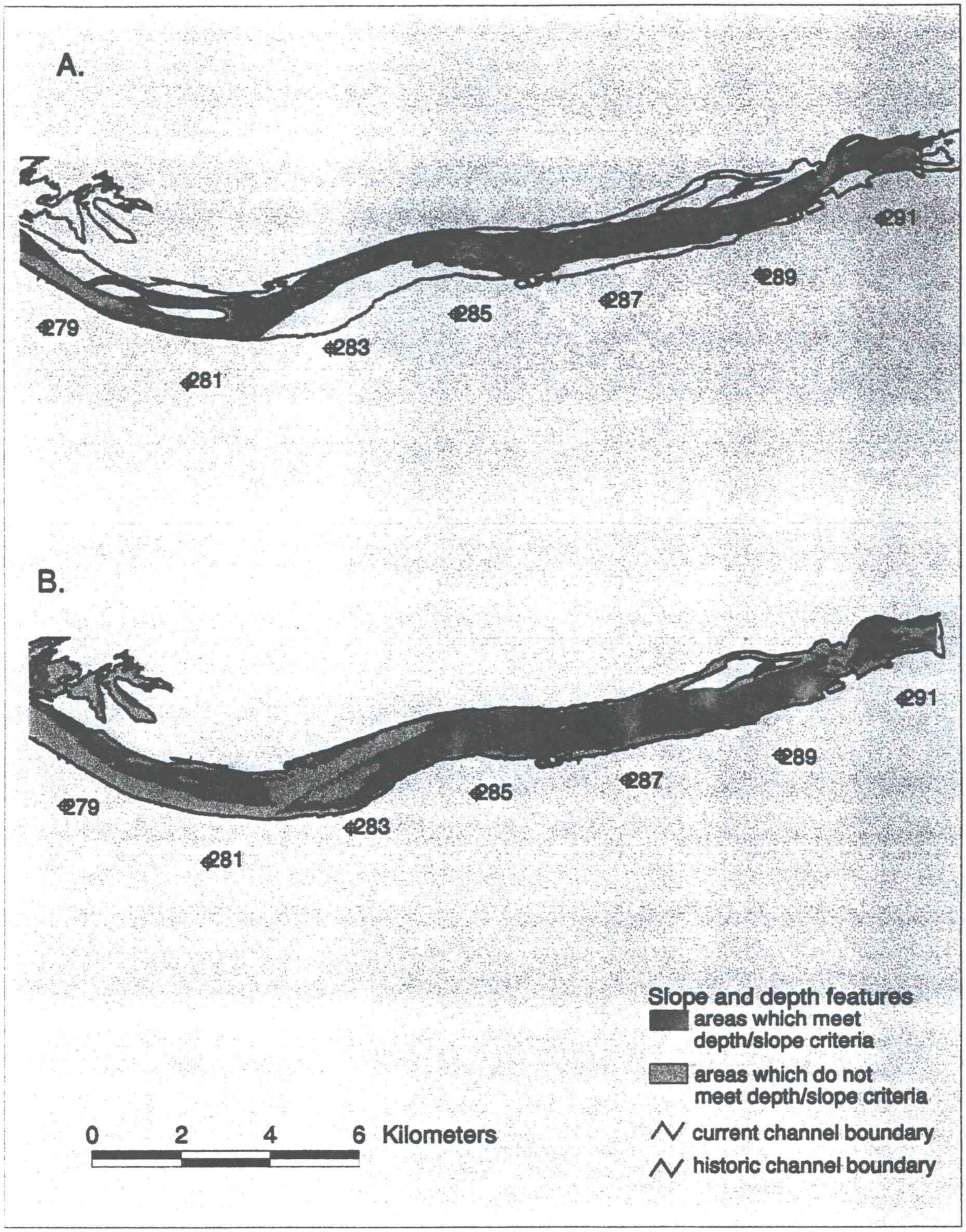

Figure B3a. Areas meeting slope and depth requirements for fall chinook salmon, upstream half of the study area (RM 277 - 292). Map A represents pre-impoundment conditions, and map B current conditions.

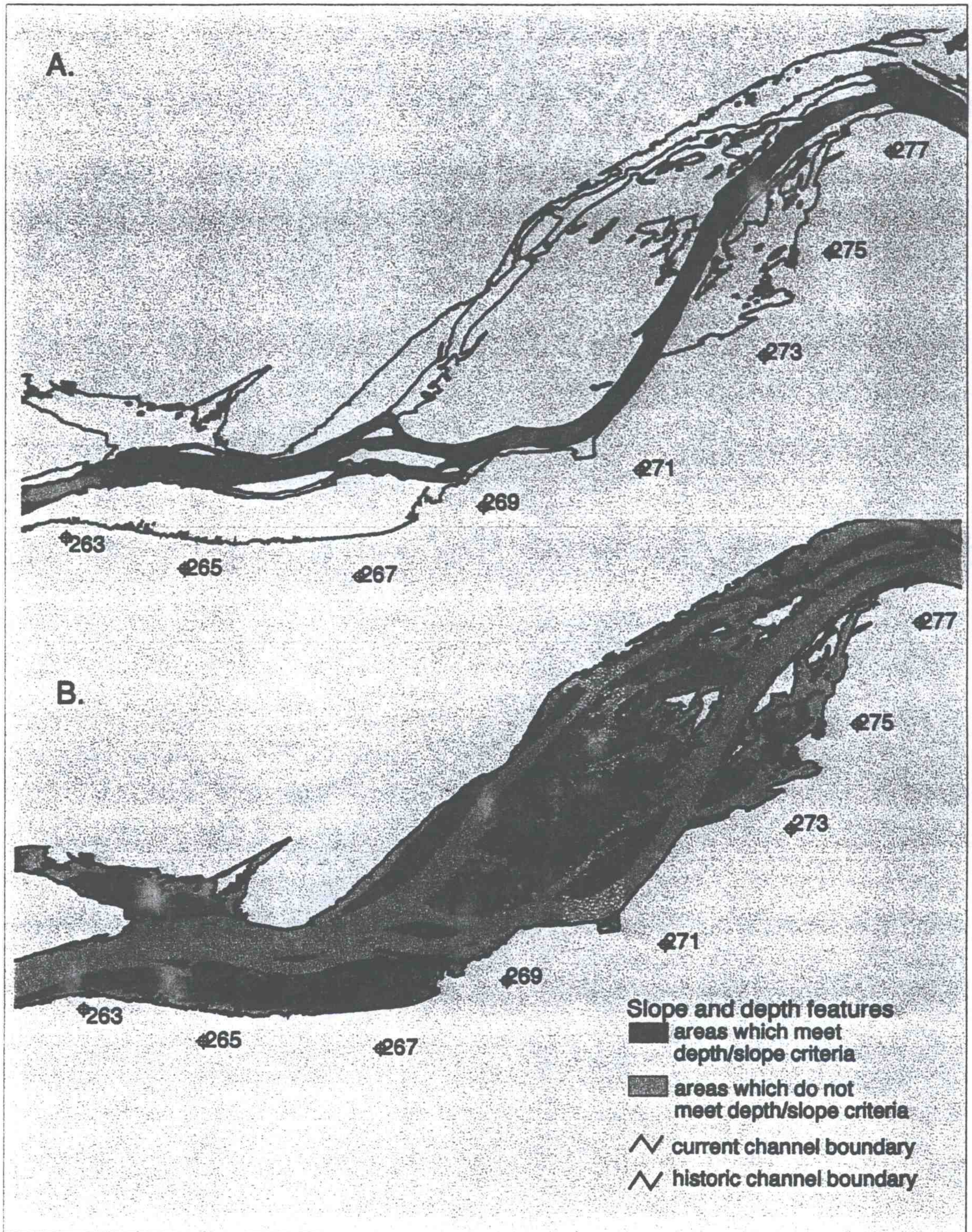

Figure B3b. Areas meeting slope and depth requirements for fall chinook salmon, downstream half of study area (RM 261-277). Map A represents pre-impoundment conditions, and map B current conditions primarily in areas which were inundated. Blalock Island and near-shore areas comprise most of the suitable habitat in the lower section. Most of the main channel areas fail the depth requirement by exceeding the 9 meter limitation. In the upper section, depth is a limiting factor, especially between RM 275 and RM 281. The lower limit of depth criteria (< 0.3 meters) is a factor in limiting areas meeting depth and slope requirements between RM 282 through RM 292.

Riverbed Aspect – Appendix B4

The aspect maps indicate differences in direction of the bed slope and riverbed complexity in the pre- and post-impoundment channels (Figures B4.1 and B4.2). The variation in aspect values from RM 282 to RM 287 in the pre-impoundment channel indicates a regular pattern of upstream and downstream exposure values, indicative of Devil's Bend Rapids and an upstream riffle (Figure B4.1). The current aspect shows variation in bed slope direction, but with less of a regular pattern than the pre-impoundment riverbed. In the original main channel south of Blalock Island, the aspect of the riverbed was exposed to upstream flows on the south shore; yet the north half of the channel sloped primarily downstream (Figure B4.2). This trend has changed so that the north shore - which is the southern shoreline of the submerged Blalock Island - of the channel is now exposed to upstream flows, and the rest of the channel has aspect values primarily sloping downstream, or away from upstream flows. The remnants of Devil's Bend and another riffle are apparent from RM 284 through RM 287, although they have been smoothed either by dredging or sediment transport.

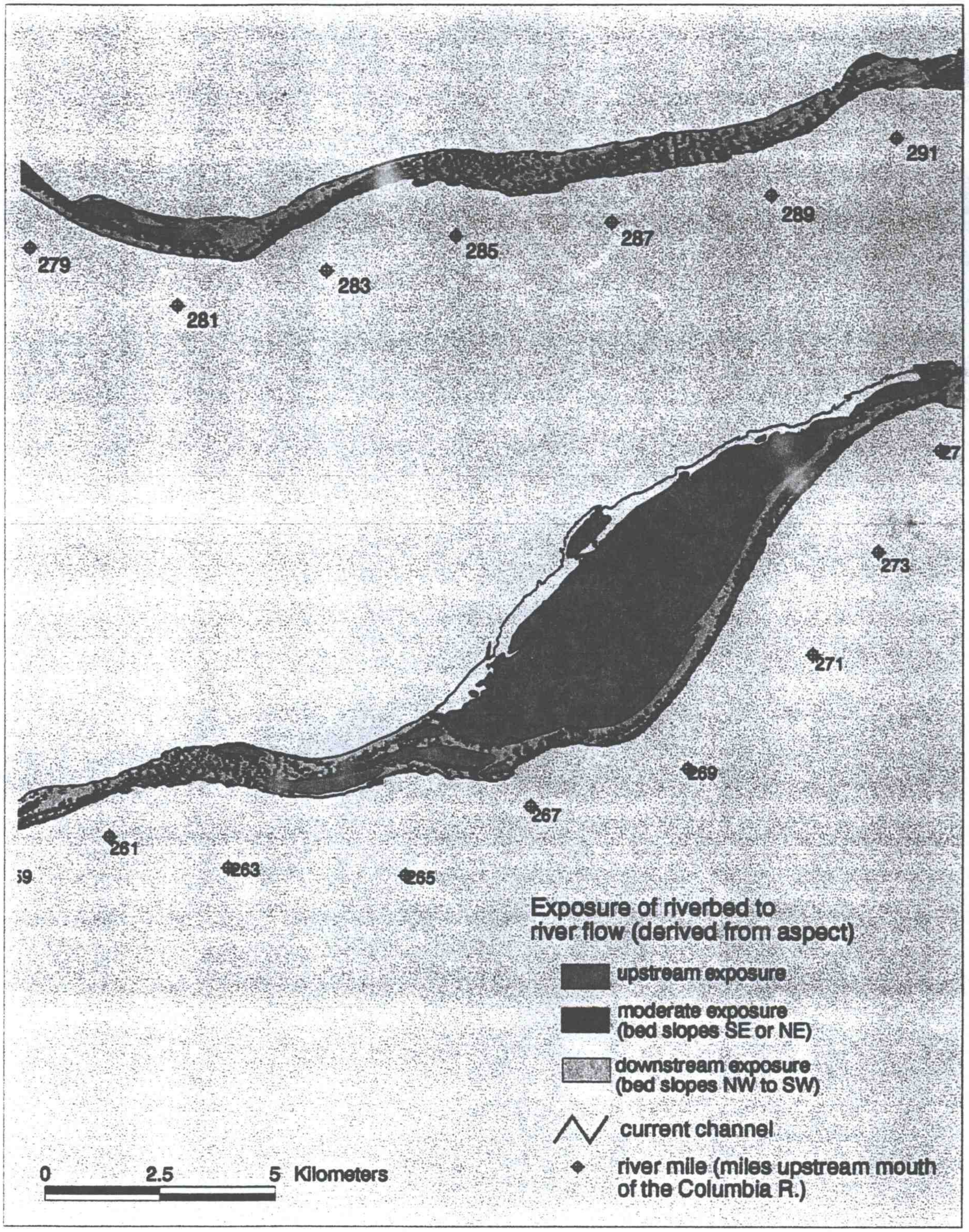

Figure B4.1 . Riverbed aspect for pre-impoundment channel conditions.

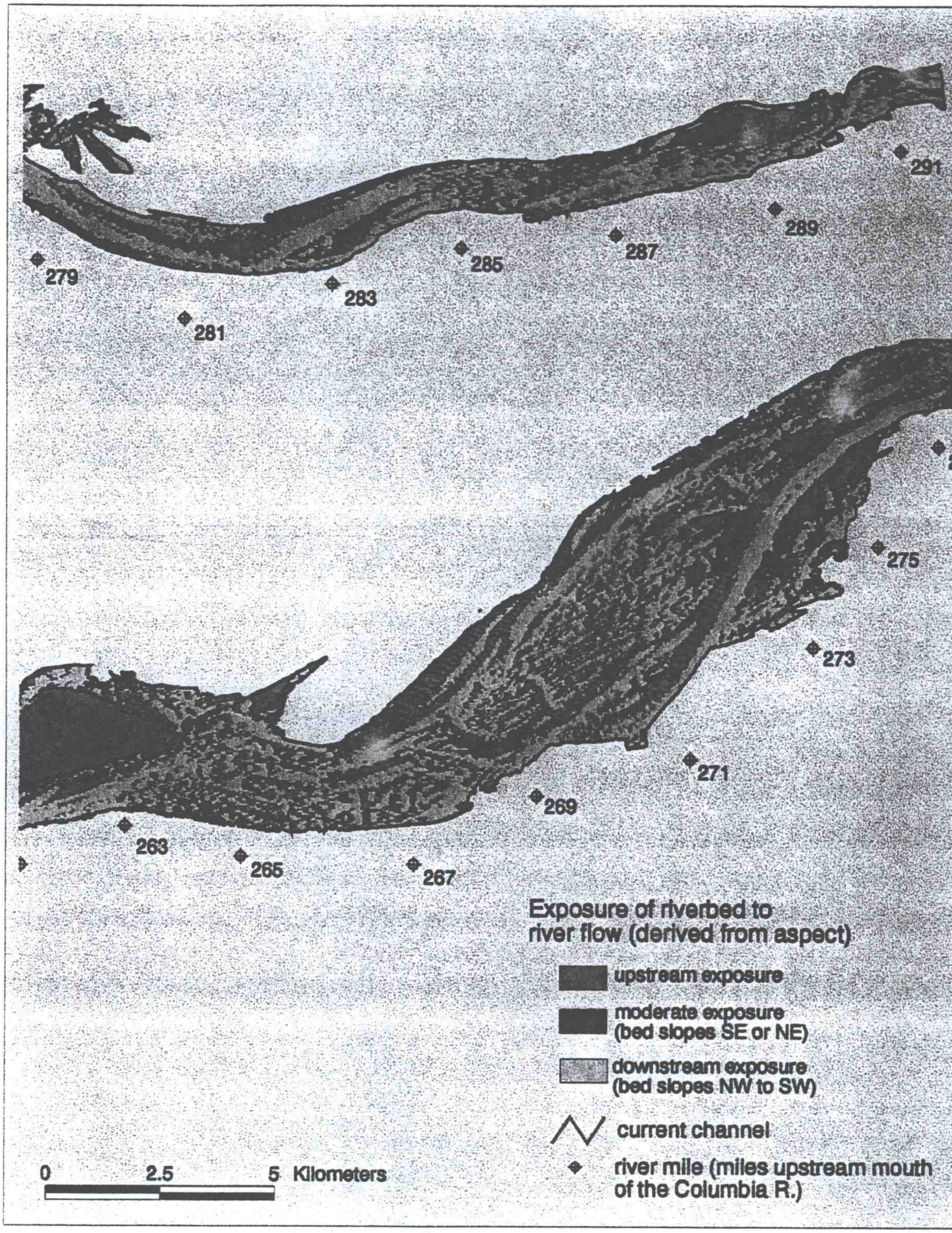

Figure B4.2 . Riverbed aspect for current channel conditions.

The locations of riffles in the river based on aspect maps give a good indication of the exposure of the riverbed to varying water velocities. Based on aspect, slope, and depth information, it is possible to divide the river into a series of habitat features for current and pre-impoundment conditions. Exposure of the riverbed is an indicator of the variation of hydraulic features in the river, but has limited usefulness without water velocity information. The addition of velocity values to aspect values would give a good indication of what areas meeting depth, slope, and substrate criteria that would also meet velocity requirements for spawning.

Preliminary Analysis – Velocity – Appendix B5

The distribution of high velocities in the current river channel is minimal for current river conditions (Figure B5.1). Only .03 %, or 2.23 hectares, of the total area modeled for current conditions had velocity values higher than 2 meters per second. The total area meeting velocity suitability requirements is 1702.43 hectares, or 19% of the total area. The remaining 81% (7258.69 hectares) of the wetted channel at 177 kcfs is characterized by low velocities less than .4 meters per second. The modeled pre-impoundment channel is comprised of 31% (1194.18 hectares) of the wetted area with velocities less than .4 meters per second, 60% (2313.87 hectares) of the wetted area meeting the velocity suitability requirements, and 10% of the total area with velocities greater than 2 meters per second.

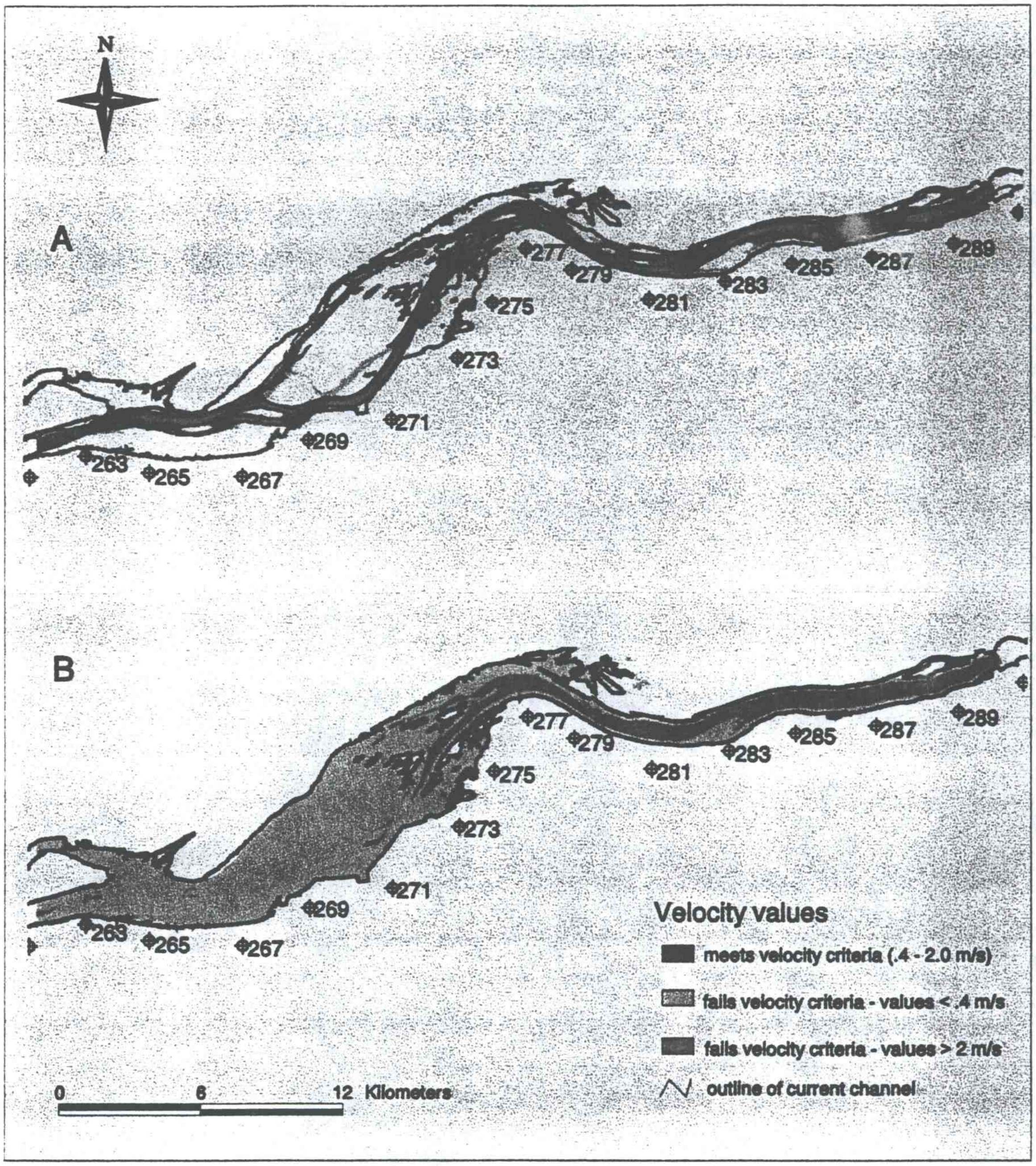

Figure B5.1. Velocity data used in this analysis is preliminary and represents a discharge of 177 kcfs, which is higher than the 50 kcfs discharge that the depth values represent in this study. Areas immediately downstream of McNary Dam were not incorporated into the velocity model, which results in the gaps that are apparent between the habitat values and the shoreline. Areas in Map A outside the boundary of the pre-impoundment river channel with velocity values are errors in modeling, and will be corrected in further modeling efforts. Map A represents pre-impoundment conditions, and map B current conditions.

The distribution of velocities for pre-impoundment conditions is correlated to river habitat features depicted in Figure 10. The areas greater than 2 meters per second are found near RM 289, RM 285, RM 281, RM 276, RM 271, RM 268, and RM 265. Based on channel and bed morphology, these majority of these areas have been classified as riffle/run sections. In most cases, the entire riffle is not comprised of velocities greater than the maximum suitable, and midchannel high velocity areas are typically bounded by suitable areas near the shoreline and immediately upstream and downstream of the high velocity patch. There are also small (< 1 hectare) patches of suitable velocity areas throughout the larger patches of high velocities, though the image resolution of Figure B5.1 does not display these smaller patches. Because of the fluctuating nature of the historical channel, and consequential fluctuation of discharge levels, edge habitats between high and suitable velocity patches may have been used, as well as areas with consistently suitable patches.

High velocity areas in the current channel are found immediately downstream of McNary Dam. There is a gap in the data immediately below the dam, which will be modeled at a later date. The section near RM 290, where the model data begins, is the only area with velocities greater than 2 meters per second for this discharge. Suitable velocity areas are distributed from this point downstream to RM 273, and suitable areas disappear in the downstream half of the study area from RM 260 through RM 273. The downstream half of the study area is typified by velocities less than .4 meters per second, which is related to the backwater effect. The velocities in both halves of the study area are consistent, with little variation or diversity of values throughout the channel. Velocities in the regulated, impounded channel do not follow the river habitat definitions depicted in Figure 10. Instead, suitable velocities gradually decrease as the water moves into the deeper, backed-up section from RM 280 through RM 273.

Substrate – Appendix B6

Most of the areas which were inundated in 1968 are characterized by fine-grained materials, such as clay, sand, or sand/clay (Figures B6a, B6b, and B6c). Many of these areas were historically comprised of sand and other fines, based on photo interpretation. In addition to the original bed materials, the presence of fine-grained sediments (< 3 cm) may have increased due to deposition in the low gradient lateral areas of the current channel. This condition is especially true in the lower half of the study area, RM 261 to RM 277, which is influenced more by the backwater effect from John Day Dam, and is deeper and wider than the upper section - RM 278 to RM 292)

Most of the islands which were flooded are now comprised of gravel or cobble/gravel, with the exception of Blalock Island which is comprised of sand, based on current substrate information and photo interpretation. In the stretch between RM 261 through RM 271, the area of the main channel is now primarily comprised of gravel, gravel/sand, and sand/gravel. The main channel in the stretch from RM 271 through RM 282 is now comprised of gravel, cobble, and gravel/cobble, and from RM 282 through RM 292 is cobble and gravel, with some cobble/boulder immediately downstream of the dam.

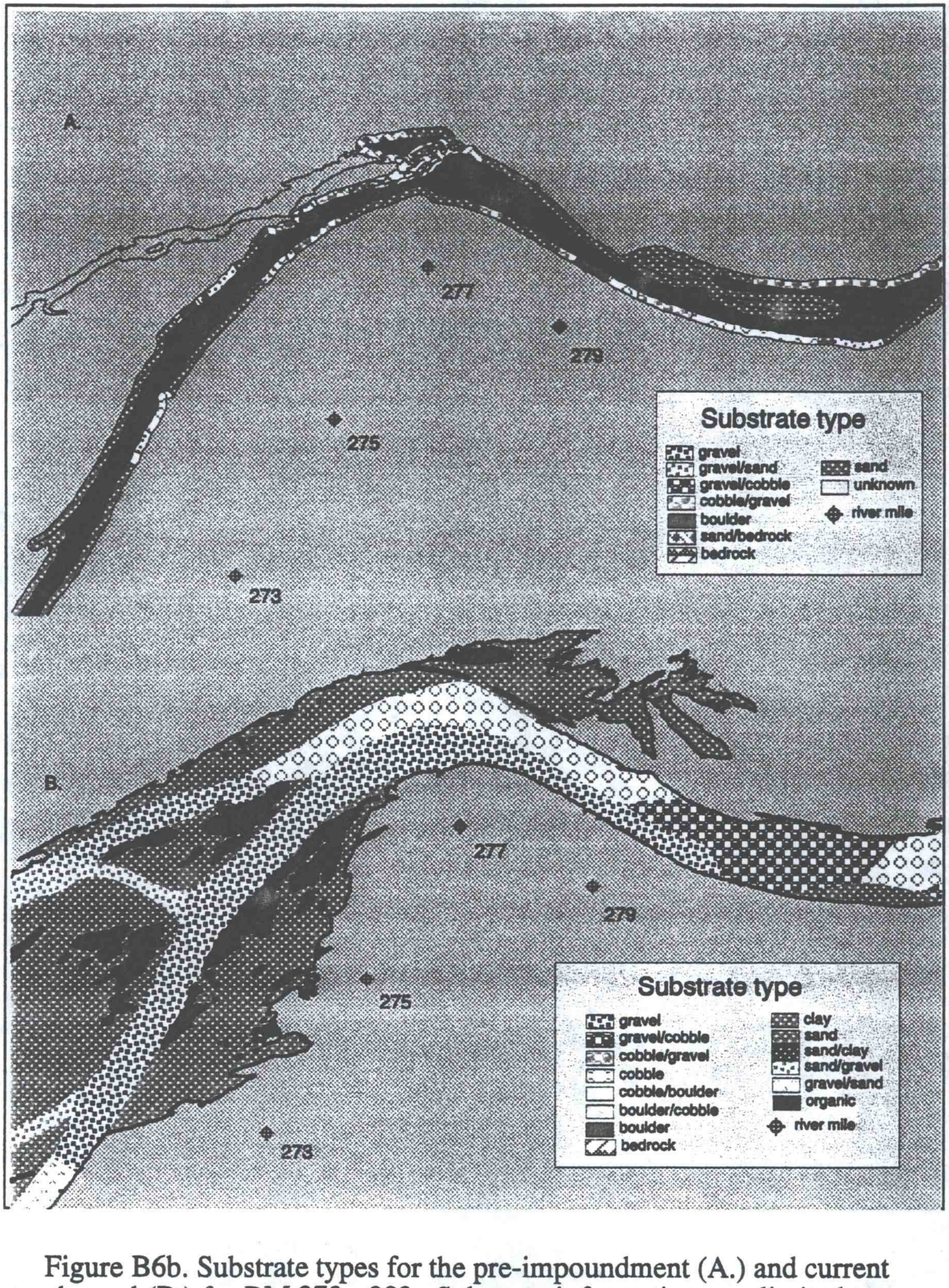

Figure B6b. Substrate types for the pre-impoundment (A.) and current channel (B.) for RM 273 - 282. Substrate information was limited to shorelines for historic conditions.

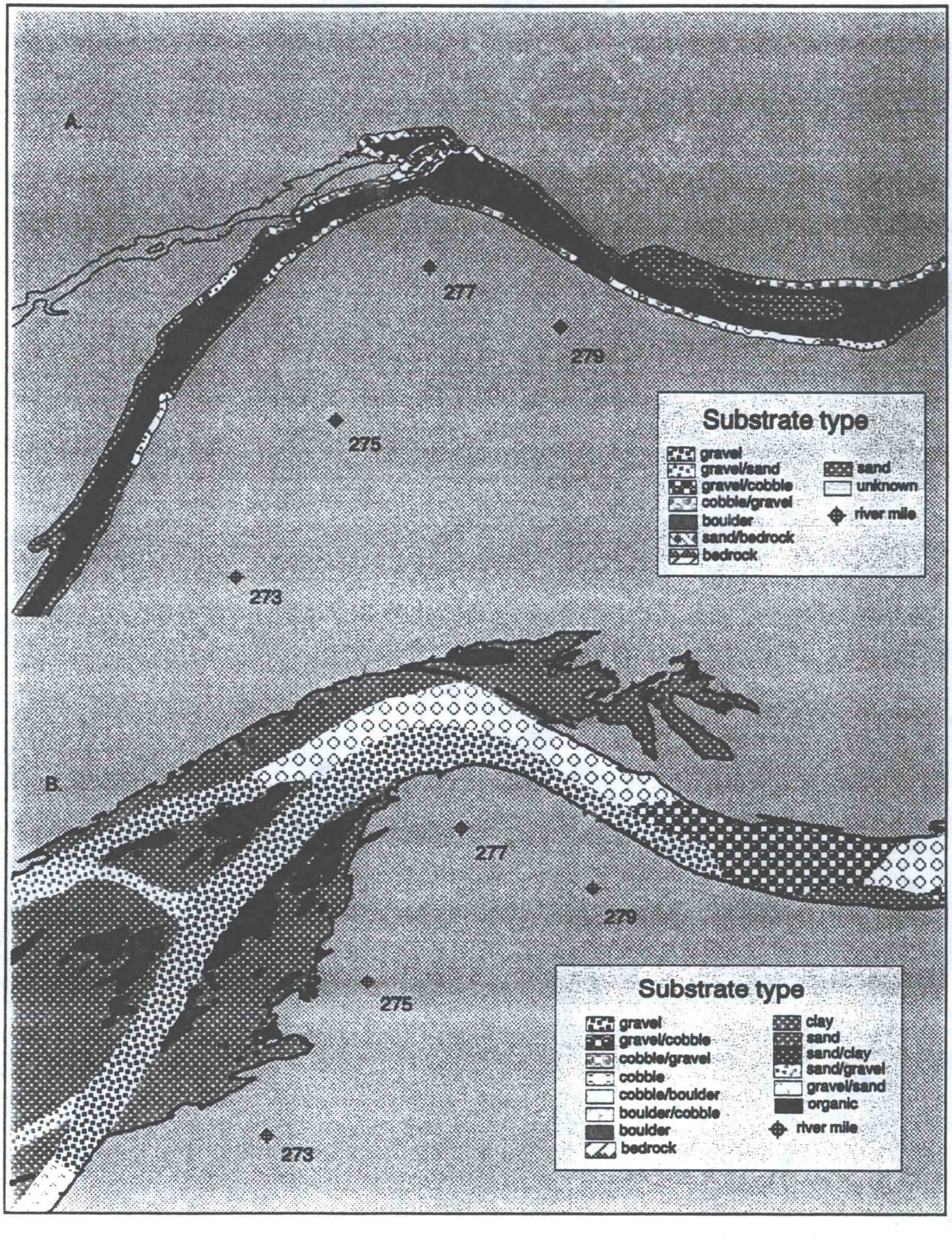

Figure B6b. Substrate types for the pre-impoundment (A.) and current channel (B.) for RM 273 - 282. Substrate information was limited to shorelines for historic conditions.

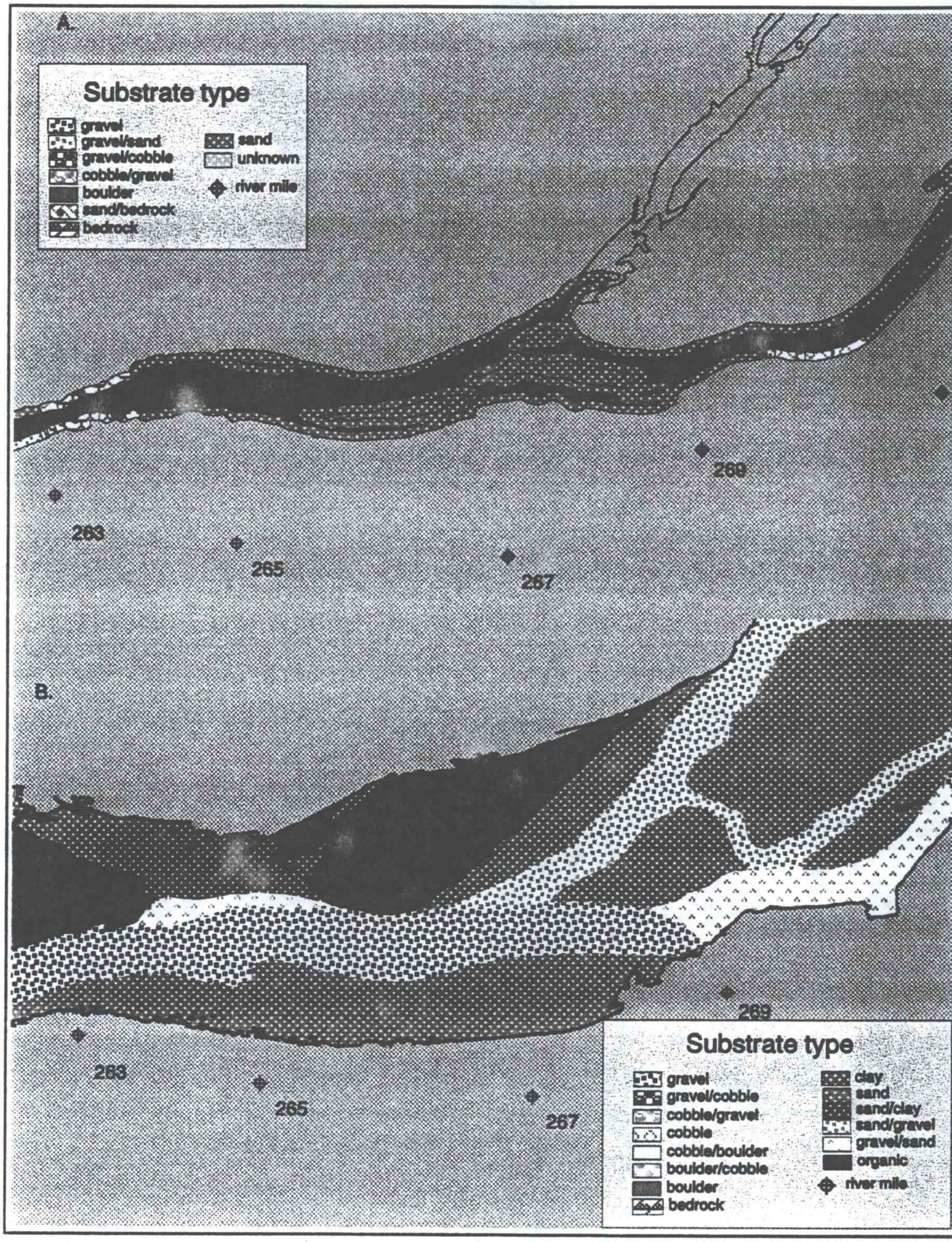

Figure B6c. Substrate types for the pre-impoundment (a.) and current channel (b.) for section C. Substrate information was limited to shorelines for historic conditions.

Most of the main channel areas, especially in the upper half of the study area, are characterized by gravel and other clean substrates, that is, not mixed with sand or clay, which is often typical of areas downstream from hydroelectric facilities. Substrates in high velocity areas typically are mixed with very small amounts of fine depositional materials because water passing through dams typically deposits fine sediments upstream of the structure, resulting in low turbidity water which then causes a high degree of scouring downstream of the structure (Itveit and Styrvold, 1984*). All areas outside the main channel that were submerged with inundation are now comprised primarily of sand, sand/clay, and clay.

Many shoreline areas of the pre-impoundment channel are documented to be comprised of sand or other fine-grained sediments. River miles 260 through 262, 268-269, 271-272, 273-275, and 277-287 are identified as having shoreline substrates larger than the sand or other fine-grained materials. Areas near RM 262, 274, 283, and 289 are characterized by exposed bedrock or sand- covered bedrock as the principal shoreline feature.