Willamette Sustainable River Project Phase 1: Development of a Monitoring Plan for Environmental Flow Recommendation on the Middle Fork Willamette River, Oregon Final Report

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By
Department of Geography, University of Oregon, Eugene, OR 97403
Contact Information: Available upon request (sustainablerivers@usace.army.mil)

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Introduction

The long term goal of this project is to initiate a monitoring program to assess physical effects of environmental flows planned for the Middle Fork Willamette River. This report covers the first phase of the project, development of a monitoring plan for the Middle Fork Willamette River that can serve as a model for other rivers in the Willamette Valley Sustainable Rivers Program. This monitoring plan is based on documentation of the environmental flow recommendations, expected effects of those flows, and other background from Gregory and others (2007a, 2007b) and Bach (n.d.). The specific focus of this report is on geomorphic, hydrologic and physical effects, which will be incorporated into a comprehensive monitoring plan/program that includes biological effects and indicators.

Development of environmental flow recommendations for the Middle Fork Willamette River downstream of Lookout Point and Dexter Dams was initiated by the U. S. Army Corps of Engineers in collaboration with the Sustainable Rivers Program of The Nature Conservancy. Following a workshop in June 2007, a set of recommended environmental flows was developed. Table 1 summarizes the high flow components of the environmental flow recommendations, specifically those flows expected to affect geomorphic, hydrologic and other physical conditions. Using this as a starting point, we completed the following tasks and the results are presented in this report.

- Compilation of a geodatabase for monitoring
- Evaluation of existing baseline data and identification of data gaps and needs
- Based on expected geomorphic and hydrologic effects of the environmental flows, identification of appropriate indicators and protocols, and of constraints and limitations for those protocols.
- Development of recommendations for indicators to be monitored and methods to be used for those indicators.

Table 1. Summary of flow recommendations for the Middle Fork Willamette River (Bach, n.d.)

Flood type	**Flow magnitude**	**Timing**	**Frequency and Duration**	**Expected effects-physical**
Winter High Flow Releases (High flow pulses)	15-19k cfs	Nov 1-Mar 15, linked to storms	1-5 events/yr, duration comparable to unreg. floods	Inundation of key channel features, secondary channels and other low lying areas
				Movement of wood
				Movement of sediment
				Changes in channel features such as in channel bars
	19-21k cfs (bankfull)	Nov 1-Mar 15, linked to storms	1-3 events every 2-3 yrs, duration comparable to unreg. floods	Increased amount of large wood w/in channel
				Inundation of key channel features, secondary channels and other low lying areas
				Increased habitat formation and maintenance above amount generated at 15-19k cfs
Small floods	25-40k cfs	Mid Nov-Mid Mar, linked to storms	not implemented	Increased transport of sediment and gravel
				Development of new pool/riffle habitat
				Creation of new floodplain surfaces through overbank erosion and deposition
				Creation of new channel and floodplain surfaces through bar development
Large floods	40-80k cfs	Mid Nov-Mid Mar	not implemented	Increased transport of sediment and gravel
				Development of new pool/riffle habitat
				Creation of new floodplain surfaces through overbank erosion and deposition
				Creation of new channel and floodplain surfaces through bar development

The study section of the Middle Fork Willamette River from Dexter Dam downstream to the confluence with the Coast Fork is approximately 17 miles (27 km) long. The river and floodplain conditions are described in Dykaar (2005, 2006), Gregory and others (2007), and Tetra-Tech, Inc. (2010). Dykaar and McConnaha (2006) divided the study section into five reaches. In most of the study section, the river has substantial floodplain with some disconnected meanders and oxbows. The channel is typically 70 to >90 m wide and up to 2 m deep. The majority of the study section has a simple single-thread channel with few bars. Revetments and other hard structures, such as railroad embankments, that cut off meanders, limit channel migration and restrict hydrologic connectivity between the channel and floodplain are are common. The potential for channel adjustment in flow events is relatively small in these areas. In contrast, there are several channel sub-reaches that are more complex and dynamic, showing evidence of change in recent aerial photo time series (for example, Dykaar 2008). We call these sub-reaches dynamic zones (Figure 1; Table 1). The dynamic zones are optimal sites for monitoring physical response to environmental flows.

Database and Data Needs

We compiled a Middle Fork Willamette River geodatabase (WRMF_Inventory_version1.gdb) of existing GIS files relevant for monitoring response to environmental flows, designed as the baseline to which future geospatial monitoring data will be added and analyzed. GIS data on physical environment and hydrography, ecology, land use, and infrastructure are included. Data came from the U. S. Army Corps of Engineers, Oregon Water Resources Department, Oregon Department of Transportation, Oregon State University, Oregon Explorer, and other sources. The geodatabase is used with a base layer of 2005 National Agricultural Imagery Program (NAIP) aerial imagery.

The geodatabase includes the following folders:

- Study Area
- Hydrography
- Historical Channel
- Bathymetry
- Ecology
- Geology_Soils
- Land Use
- Transportation

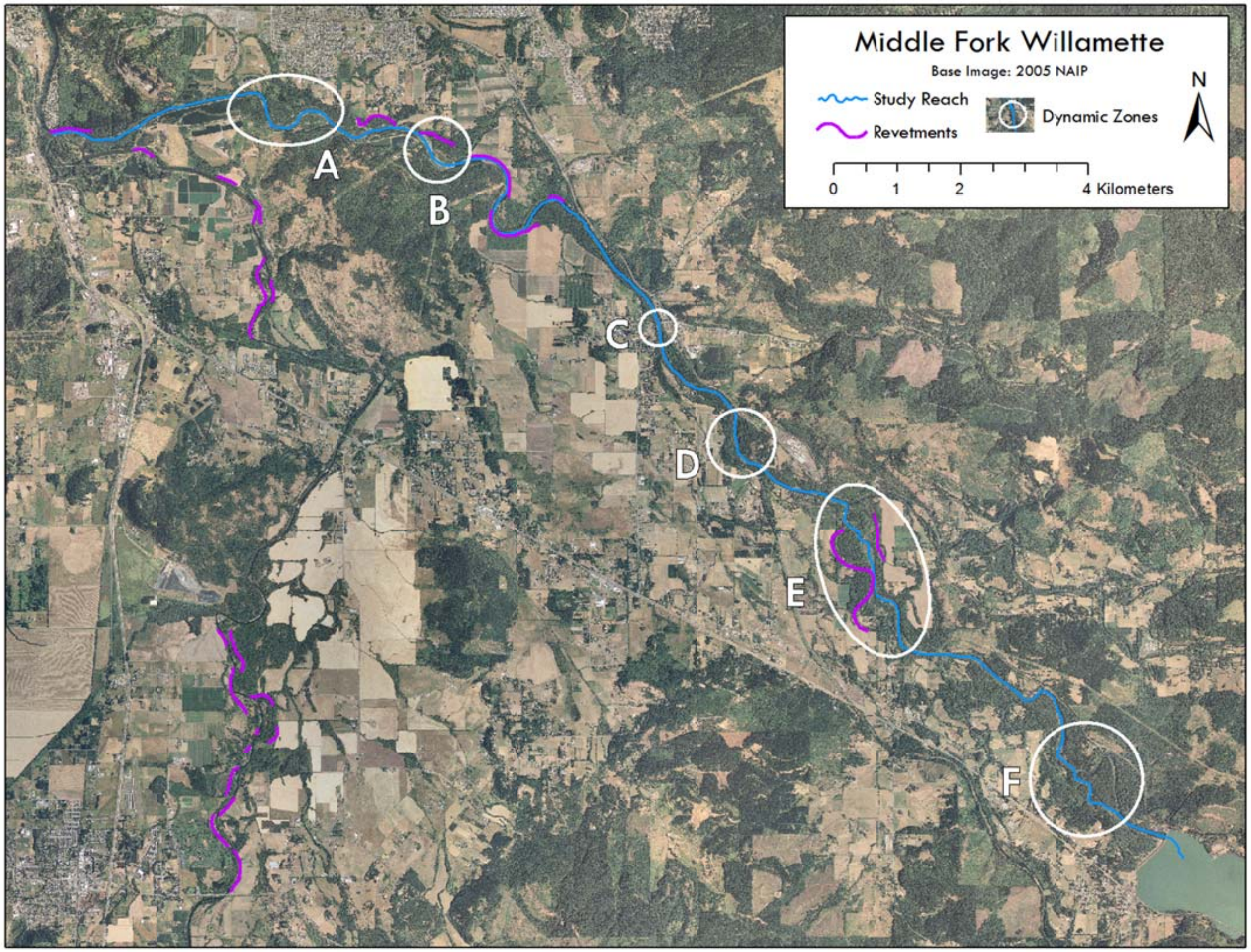

Figure 1. Map of the study section of the Middle Fork Willamette River. See Table 2 for information on dynamic zones.

Table 2. Locations of dynamic zones suitable for monitoring sites.

Zone	Approximate river mile	Location
A	189-190	Willamette Confluence property (TNC)
B	192	Willamette Confluence property (TNC); just upstream of Clearwater Park
C	195	Jasper bridge
D	197	Downstream of railroad bridge
E	198-200	Fall Creek confluence and upstream
F	205	Elijah Bristow State Park

All of the shapefiles and layers have been clipped to the study area. The Files folder contains a detailed list of the individual files and a brief description of the information contained therein. These categories will be useful as more data is added. The geodatabase contains available data closest in time to the implementation of the environmental flows plan. New data should be added in the future with these existing data types and formats in mind so that they are comparable. There is a significant amount of useful data that is not in GIS format but will be useful for future analysis, located in a folder named Additional Files.

Since the data were compiled from a variety of sources, there is variation in resolution and accuracy. The data were created by different organizations and individuals without a common standard. For example, when the most recent channel line (1995) is overlaid on the most recent imagery (NAIP 2009), there are discrepancies because the channel has changed in the intervening years. Similarly, the rock and gravel mine/pit information is dated 2004 and there may have been changes with respect to their size and location since that time. The quality of metadata varies among these files, and for some files no metadata were available.

Some data types that would be useful in the project are not available to our knowledge. We were unable to obtain any GIS vector data on previous channel boundaries, although some data of this type are described and presented in Dykaar and McConnaha (2006; 2008). These data could be created from older imagery if resources allow. There are no LIDAR elevation data available for the floodplain. LIDAR data would very useful for evaluating inundation and also for channel morphology. In the future, LIDAR may become a key technique for monitoring channel change. Assuming a good bare earth model can be obtained, channel margins can be detected more accurately under tree canopy with LIDAR than with aerial imagery.

Recommendation: We recommend that LIDAR coverage of the study area channel and floodplain be acquired if resources allow.

New data will need to be added in a similar structure, and the topology for comparison will need to be developed. Knowledge of the data acquisition methods will be important in determining and setting up the topological structure at that time. It will also be important to develop strong metadata for data created or acquired for this project.

Monitoring Indicators and Methods

Channel morphology and sediment movement

Expected physical effects of the recommended environmental flows for the Middle Fork include changes in both processes (sediment movement) and morphology (bars, pool-riffle and other types of habitat, and channel and floodplain surfaces) (Table 1). While it is possible to monitor sediment movement directly through the use of tracer gravels, scour chains and other methods, these approaches are time intensive and require critical scheduling to conduct field sampling shortly after a flow event. We recommend the approach of monitoring the morphological effects of sediment movement rather than the process of sediment movement.

Channel morphology characteristics that are good candidates for monitoring include wetted or active channel boundary, extent of floodplain surfaces adjacent to the channel, and bar area and location. Channel morphological monitoring begins with mapping boundaries of the channel and other features. Once the boundaries are mapped in GIS, a number of indicators of change can be measured or calculated.

Mapping methods

There are two general approaches to monitoring channel morphological changes over time – ground-based measurement in the field and mapping change over time from aerial imagery in GIS. The advantages and limitations of ground-based and aerial image methods for mapping various morphological characteristics are summarized in Table 3. A guiding principle for this monitoring plan from the outset was to keep the monitoring approach simple and relatively low cost. The review summarized in Table 3 led us to conclude that monitoring morphological changes by mapping from available aerial imagery would be effective at lower cost than contracting for imagery or relying on field mapping.

Recommendation: We recommend mapping from aerial imagery in GIS for monitoring channel change on the Middle Fork Willamette.

Channel boundaries and other features are typically mapped from aerial imagery, by manual digitizing. An advantage of mapping from imagery in GIS is that older imagery can also be mapped, allowing development of data that predates the present monitoring effort and even predates flow modifications at the dam. Thus a before-and-after data set for channel morphology can be developed. The standard imagery used in this kind of river mapping is U. S. Geological Survey digital orthophoto quadrangles (DOQs), which are available for Oregon from 1994-95 (1-m resolution), 2000 (1-m resolution), and 2005 (0.5-m resolution); or the U. S. Department of

Table 3. Summary of aerial imagery and ground-based alternatives for monitoring channel morphological change.

Indicator Variable	Approach	Data acquisition	Analysis	Resolution/ Accuracy	Comments (pros and cons)
a) Wetted or active channel	Aircraft	Map from true color or black & white	Manual digitizing; compare polygons across years	≤1.0 m	Can use historical imagery as well as future repeat imagery Differences in Q from year to year complicate comparisons
	Ground	Map boundary by GPS walking	Compare position of bank top across years	≤1.0 m	Post-field processing relatively simple; Difficulty traversing wooded areas; More limited spatial extent than imagery
b) Bars & floodplain surfaces	Aircraft	Map from true color or black & white	Manual digitizing; compare polygons across years	≤1.0 m	Cannot map bars in heavily forested areas that make up much of MFWR. Can use historic imagery.
	Ground	Topo transects; total station or GPS survey	Topography; calculate scour, deposition across years	≤0.1m	Post-field analysis requires moderate amount of effort; Difficulty traversing wooded areas More limited spatial extent than imagery
c) Secondary channels	Aircraft	Topo and boundaries from true color, black & white, or LIDAR	Baseline mapping of existing secondary channels	≤1.0 m	LIDAR may be more accurate if a good bare earth model can be constructed. Will not necessarily be repeated for monitoring.
		Map features by GPS walking; Measure water depth (at sill)	Detect changes in degree of connection	≤1.0 m	Purpose is to monitor changes in degree of connections of secondary channels to main channel, over time.
d) Bed morphology; pool/riffle	Boat	Sonar or ADCP	DEM difference	≤0.1 m vertical	By Corps, or contract out

Ground

Agriculture NAIP imagery (2009, 0.5-m resolution). The 2011 NAIP imagery for Oregon is soon to be released. Future imagery will probably be produced at five year intervals or perhaps more frequently. To extend the record back in time, older film-based aerial photos can also be used for mapping river features, with imagery flown at 1:30000 or higher resolution. A disadvantage of mapping based on available imagery is that the date and year of monitoring cannot be controlled, unless an aerial image flight is ordered specifically for the project. But with the frequency of image acquisition today, this is not a major disadvantage.

Quality control procedures for mapping channel and floodplain features from aerial imagery include a) use of a protocol that includes definitions for each type of feature boundary to be mapped; b) review of mapping by a second qualified geomorphologist on the team; and c) checking a subset of mapped boundaries on the ground. The ground-truthing procedure would involve selecting several small areas representing a diversity of features, and visually examining boundaries in the field with printouts of the mapping at scale of around 1:1000. We believe that the accuracy achieved in mapping landform boundaries (such as the active channel boundary) from 0.5m imagery is $\pm$1 to 3 m (see discussion below). Only responses to environmental flows that are greater than this can be detected. More discussion of accuracy and quality control issues is found in the following sections on specific landforms.

Alternatives to mapping channel features from imagery include a) direct measurement of changes at specific sites, such as channel cross-sections; and b) mapping them in the field with GPS by walking the boundary of the active channel. Direct measurements of landforms, such as repeat measurements at cross-sections, is a traditional approach that is being displaced by the advent of high resolution aerial imagery (Carbonneau et al. 2012). For large non-wadeable rivers such as the Middle Fork Willamette, direct field measurement is difficult and time-consuming. Direct field measurement achieves higher accuracy and change detection than mapping from imagery, but geomorphic change in the Middle Fork Willamette is likely to occur at the scale of meters, so the high accuracy may not be required to detect change. Direct measurement covers only points or transects, while mapping is spatially extensive and continuous.

Field mapping of landform boundaries is more time consuming than mapping from aerial imagery. With field mapping, the length of channel covered would necessarily be significantly smaller than what could be mapped from imagery. Problems might be encountered in the field with moving through thick brush or woody debris accumulations. Permission for access from private property owners would need to be established in advance. Field mapping also requires decisions on the location of the landform boundary to be made in the field. The field view may be too close, and landform boundaries are often easier to identify from aerial imagery than in the field. Quality control procedures for field mapping might include preliminary mapping from imagery before going in the field, use of imagery while mapping in the field, and written criteria for identifying the boundary. The horizontal accuracy of field mapping would probably be similar to that of mapping from imagery. If mapping from imagery proves to be problematic, a sampling plan involving field GPS mapping of active channel edge (both main channel and secondary channel) at selected sampling reaches could be implemented.

Procedures for mapping river active channels and other features from imagery have been developed by Pacific Northwest Ecosystem Research Consortium (2000), O'Connor et al. (2003), Rapp and Abbe (2003), Dykaar (2005), and Hughes et al. (2006), and the procedures are generally consistent among these sources.

> **Recommendation: We recommend that a procedure for manual digitizing and ground-truthing of features that are mapped be written as the first generation of mapping is done for the Middle Fork Willamette.**

Active Channel Boundary

The most important feature to map and monitor is the channel boundary, because it provides the framework to identify inundation of off-channel areas, habitat formation, creation of new floodplain surfaces, and changes in bars (Table 1). To consistently map channel boundaries from aerial imagery, it is critical to conceptually define the features. The wetted channel boundary is the submerged/subaerial surface boundary that is visible on the ground or in aerial imagery. The wetted channel boundary varies hourly to daily as discharge fluctuates. The wetted channel boundary shifts laterally from year to year as discharge on the date of imagery acquisition varies. Changes in the boundary of the wetted channel may primarily reflect discharge differences rather than morphological change. In contrast, the active channel is defined by morphology, independently of the discharge level. It is "the portion of the river and floodplain inundated at normal winter flood flows (i.e., those with an average return interval of one to two years)" (Pacific Northwest Ecosystem Research Consortium, 2000). The active channel includes channel threads that flow perennially, threads that are dry part or most of the year, bars, and other low active surfaces. Active surfaces are those experiencing fairly frequent (every few years) sediment erosion and deposition. Active surfaces covered with sparse to moderate cover of annual plants and grasses, and sparse young riparian shrubs, typically are included within the annual channel, while surfaces with more permanent and denser vegetation cover are excluded from the active channel.

> **Recommendation: We recommend that monitoring for the Middle Fork Willamette River focus on the active channel boundary rather than the wetted channel boundary.**

The active channel boundary is somewhat difficult to define and requires some judgment in mapping. The challenge is to ensure that criteria for defining the active channel boundary are consistent in future years of monitoring. One issue is deciding which vegetated surfaces to include within the active channel and which to exclude. Elevation of the surface can aid in making this decision on the aerial imagery. The 10-m resolution DEM currently available can be used for this, but high resolution elevation model for the floodplain from bare-earth LIDAR would make mapping the active channel boundary easier and more consistent. A second issue is the problem of overhanging tree canopy that obscures the active channel boundary. In this case, mapping usually follows a rule such as drawing the active channel boundary one-third of the way in from the tree canopy edge. By recording detailed criteria used, we believe an acceptable level of consistency in mapping can be achieved. Another alternative is to designate accuracy levels (high, medium, low) for specific segments of the boundary as it is mapped in GIS. The horizontal accuracy of active channel boundary mapping will range from ±1m in ideal conditions (no overhanging vegetation) to about ±3m when tree canopy obscures the boundary. It is feasible to map the active channel boundary for the entire 17-mile long study section for each year of imagery, or selected reaches could be mapped.

Secondary channel boundaries and other floodplain features

Secondary channels are side channels that may flow perennially or intermittently. They are separated from the main channel by floodplain surfaces (relatively stable surfaces with permanent vegetation cover). Threads of the main channel that branch around bars without permanent vegetation are considered part of the main active channel; see above. Secondary channels may experience a range of stability levels. Those with a relatively low threshold elevation at the inlet, and a more open inlet may respond to annual to decadal-scale floods. Secondary channels with high threshold elevations and narrow or oblique inlets may change very little over decades.

In addition to secondary channels, it may also be useful to map other floodplain features. There are a number of gravel mines on the floodplain of the study reach, and these features are important because of the potential for hydrological connectivity and as potential restoration sites. Furthermore, there may be other off-channel water features on the floodplain. While these may not be subject to frequent change, mapping gravel mines and off-channel water features provides a context for evaluating channel and floodplain changes over the long term. Finally, mapping the floodplain boundary (outer edge; contact with upland) is also useful for defining the domain within which geomorphic and habitat changes may occur.

Accuracy and quality control issues for secondary channels and off-channel water features are similar to those for active channel boundary. GIS coverage for gravel mines is available from previous studies under the Middle Fork Willamette Floodplain Restoration program.

Bars

Bars are sediment accumulations within the active channel and include attached bars, point bars, and mid-channel bars. Bar sediments are easily and frequently mobilized, making bars valuable monitoring indicators. The bar boundary is usually mapped as exposed (subaerial) area above the water line in aerial imagery or in the field. The bar extends underwater and there is no absolute lower boundary to the bar that can be consistently mapped from year to year to measure changes in bar area.

Monitoring changes in bar area and location presents special problems. Bars can be mapped from imagery, as described above for channel boundaries. Extracting bar area from imagery mapping has the problem of variation due to differences in discharge and stage rather than morphological change in bar area. Despite this, bar area is important and it is often mapped from imagery in river analysis projects. It is possible to adjust wetted-boundary bar area to correct for differences in discharge and stage on different image dates using data on bar slope derived from LIDAR or field measurements, although higher error is introduced with the correction. Another approach to quantifying changes in bars is simply to count bars and calculate bar frequency per kilometer. Yet another approach is simply to track the existence or movement of individual bars by comparing their appearance in imagery across years.

Bars can be monitored directly in the field by topographic surveying (subaerial portion) and bathymetric surveying (subaqueous portion). This approach eliminates the problem of differences in water stage from year to year. As for secondary channel inlets, survey-grade GPS is the best technology for the subaerial portion of this monitoring. The exposed topography of the bar would be measured, and surveying could be extended by wading to about 1m below the water surface. The sampling scheme could be either transects across the bar or a TIN survey of the entire bar surface or a portion of it. If funding is available, bathymetric survey data could be obtained by contract and merged with the subaerial survey data. With repeat survey data, changes in a bar could be monitored using a difference of DEM approach, in which the DEM from year 1 is subtracted from the DEM of year 2 to obtain areas and depths of erosion and aggradation (Milan et al., 2011). This approach is likely to be more time consuming and expensive than mapping from aerial imagery.

> **Recommendation: We recommend doing a trial of imagery mapping and field mapping in a small area, to evaluate the effort needed, achievable accuracy, and problems of the two methods for bar monitoring. The plan for bar monitoring should be based on this trial**.

Analysis of channel morphological change

When channel boundaries and other features are mapped in GIS, width and area measurements can be extracted, shifts in channel boundary over time can be measured, and areas lost or gained by the channel over time can be calculated. Potential monitoring indicators for channel morphology are listed in Table 4.

Large wood

It is expected that the planned environmental flow releases will both mobilize large wood and increase the amount of large wood within the active channel (presumably by recruiting wood from banks and the floodplain). Therefore it is important to monitor both the movement of wood and the total volume of wood within the active channel. There are significant challenges in monitoring large wood in rivers in an efficient and low cost way. Approaches that have been used to monitor large wood include field labeling and subsequent counting of individual wood pieces, and mapping large wood pieces and accumulations on standard aerial imagery (such as USGS or NAIP). The wood labeling approach is costly in terms of field time and labor. Also, there is risk of a high failure rate in relocating labeled wood pieces in subsequent years. The U. S. Army Corps of Engineers has conducted some monitoring of large wood movement on the Middle Fork Willamette using this technique (G. Taylor, pers. comm.).

Table 4. Potential monitoring indicators

Variable	***How measured/calculated***
Active channel width	Extract at transects across the channel; calculate reach average width
Active channel area change	In GIS overlay, measure area lost, area gained and net area, by reach
New floodplain area created	Area abandoned by active channel
Bar area	Above-water bar area; can be corrected for stage
Bar elevation loss/gain	Field survey (GPS/bathymetry) and difference of DEM analysis
Bar frequency	Count of bars per km or mile
Bar loss/gain, movement	Overlay 2 years of imagery and rate each bar as lost, created, moved (upstream or downstream), or unchanged
Secondary channel length	Construct channel centerline and measure
Secondary channel area	Same as for active channel area
Inundation extent	Develop inundation surface from stage gages; Map area inundated and number of off-channel features (i.e., dry channel, water bodies) inundated or connected by a specific flow event
Large wood loss/gain	Count individual pieces of wood in photographs or imagery for individual large wood accumulations
Large wood accumulations	Map and count accumulations and determine gains or losses of accumulations

The standard aerial imagery approach is limited in effectiveness, because wood pieces are typically less than 0.5 m in diameter. Also, tree canopy often obscures wood. New technologies are coming on line that might be applied to large wood monitoring. For example, high resolution photography (often 20cm pixels or better) from balloons or low altitude unmanned aerial vehicles (UAVs) (mini-planes and helicopters) can be taken of individual wood accumulations or short reaches in the field. Heavy tree canopy also can be a limiting factor in this technology.

A new approach that might be effective in monitoring large wood is to take ground-based, hand-held photography of a wood accumulation from all sides, and use software to stitch together the imagery to create a 3-D model of the accumulation, called structure from motion (Robertson and Cipolla 2009; Wikipedia, n.d.). Repeat photography and modeling in future years would allow comparison of the wood accumulation and censusing individual pieces. It is not clear what would be the best approach for large wood monitoring on the Middle Fork Willamette at this time. Indicators that might be developed for large wood monitoring include tracking the gain or loss of accumulations, and tracking the number of wood pieces in individual accumulations (Table 4).

> **Recommendation: We recommend testing labeling, aerial imagery mapping and ground-based photography techniques for large wood monitoring to evaluate feasibility and quality of results. Large wood monitoring by labeling conducted by the Corps will be compared to these techniques to select a monitoring method.**

<u>Inundation</u>

High flow releases are expected to inundate secondary channels and other low lying areas (Table 1). The potential monitoring indicators for inundation are stage and duration of inundation related to a specific flow release. Features relevant for inundation monitoring are dry much of the time and inundation will be short lived, so timing of monitoring is critical. To accomplish time-critical monitoring at multiple sites throughout the 17-mile section, the most suitable technique is a) crest-stage gages or b) pressure transducers with automatic data loggers. A crest-stage gage consists of a vertical perforated pipe, an inner stick or height indicator, and a floatable indicator such a ground cork that floats upward as the pipe fills and adheres to the stick (U. S. Geological Survey 2003). Data are collected by visiting the gage and reading the height of inundation on the stick. Crest-stage gages are typically read annually or seasonally. They are inexpensive to construct. Their drawbacks are that they record only the peak stage reached since the last reading, and do not record the date of that stage, its duration, or any lower stages that may have inundated the features of interest. Pressure transducers with automatic data loggers (for example, Campbell Scientific, n.d.) are more expensive but provide continuous data logging (at hourly intervals, for example). They can be read either by seasonal site visits to download data electronically, or by automatic data transmission to an office using cellphone, radio or satellite connections. The U. S. Army Corps of Engineers has a network of pressure-transducer stage gages (Hobos) along the main channel of the Middle Fork. The Nature Conservancy has pressure transducer gages installed at the Confluence Preserve (near the downstream end of the study area; L. Bach, pers. comm.). In addition, Oregon Department of Fish and Wildlife has piezometers that respond to stage at secondary channels as part of its chub monitoring project (G. Taylor, pers. comm.). The spatial distribution of these existing gages should be evaluated, and additional gages should be installed only if there are areas or important features not represented in the present network of sensors.

> **Recommendation: We recommend use of pressure transducers to monitor inundation in secondary channels and other low-lying areas. Monitoring should be based on the existing gage network. The existing network should be evaluated to determine if new gages need to be added to provide adequate coverage.**

The frequency of flow into secondary channels depends on the sill elevation and width of the secondary channel inlet. A complementary approach to stage monitoring is to monitor the elevation of secondary channel inlets and outlets. Inlets and outlets are likely to be the most dynamic portion of the secondary channels, and are good candidates for monitoring.

Field monitoring by topographic surveying would be required. The best survey tool for this is survey-grade GPS, which obtains easting, northing, and elevation coordinates to approximately 1 to 3cm accuracy. The Middle Fork Willamette is covered by the Oregon Real Time GPS Network which would allow surveying to be done without a base station. Assuming the secondary channel is wadeable during the low flow season, either cross-section transects or areas of the channel could be surveyed at the inlet, and outlet if desired. It would be advisable to survey an area at the inlet covering the bank tops and inlet bed, and extending 30 to 50 m downstream in the inlet. If cross-sections are surveyed, cross-sections from subsequent years would be overlaid to measure amount of aggradation and scour in the cross-section. Monumenting cross-sections with rebar allows the same line to be re-occupied in subsequent years. If areas are surveyed, a difference of DEM analysis (see Bars, above) should be done. With DEMs from subsequent years, a difference of DEM analysis could be conducted to determine areas and volume of erosion and scour.

> **Recommendation: We recommend field-based monitoring of secondary channel inlets and outlets if time and resources allow.**

Sampling Design and Implementation Decisions

Implementation of this monitoring plan depends heavily on costs associated with each desired indicator and method. All of these methods require some initial testing to ensure that they will work on the Middle Fork Willamette and to estimate the time and cost to implement them. Some proposed methods are experimental and require field trials. The recommended monitoring procedures should be prioritized and cost estimates made for each one, to determine which can be supported.

Frequency of monitoring is also a critical implementation decision that is related to costs, available funding and project goals. We propose initial monitoring frequencies in Table 5, based on both practical considerations and the need to answer hypotheses about flow releases (see Table 1). The interval between collections of monitoring data could range from one year to five to ten years or more. With the implementation of a new management mode (such as environmental flow releases), in general we expect relative rapid response in the first few years and decreasing rates of adjustment as times goes on. Therefore, ideally monitoring is done more frequently in the first few years after implementation. Also, monitoring that is frequent enough to capture effects of specific flow releases is important because it allows testing of hypotheses related to specific flow event sizes. For example, a five year monitoring interval that included two high flow pulses (16,000 to 20,000 cfs) and one small flood (25,000 to 40,000 cfs) would not allow identification of the effects of the high flow pulses. Thus managers could not draw conclusions about whether high flow pulses are effective and should be continued as planned or modified. When one of the larger releases (such as a small flood) occurs, it is important to monitor shortly after the event (same year) if possible. This allows both capturing the effects of the high flow event, and separating the effects of subsequent smaller events from the large event. Monitoring of secondary channels may be done less frequently than monitoring of the main channels because secondary channels are generally less active and more stabilized. If monitoring can be done only at longer intervals, it will still be possible to detect trends and cumulative effects of the flow releases. The frequency of monitoring based on aerial imagery, such as the channel and bar response monitoring recommended in this report, is controlled by the frequency of available imagery. In recent years, high quality digital imagery has been obtained by government agencies such as the U. S. Geological Survey and the U. S. Department of Agriculture every two to five years, so fairly frequent monitoring will be possible if imagery acquisition continues at the same pace. In contrast to monitoring from imagery, monitoring of flow inundation from gages and piezometers will capture each flow release individually, because the data are collected daily and continuously. Finally, as monitoring data are analyzed in the first five years of the program, evidence will accumulate on the responsiveness of the river system. The monitoring interval should be adjusted as this understanding of the system grows.

Potential sites suitable for each indicator and method can be identified using the available GIS layers. The dynamic zones (Fig. 1; Table 2) represent a first attempt to select suitable areas for monitoring sites. Monitoring sites can then be selected to cover representative features and achieve a good spatial distribution going downstream along the study section. Monitoring sites should also be selected to cover a range of different types of features. For example, monitoring sites for inundation should be located on secondary channels representing a range of inlet elevations. Access will also be a factor in selecting monitoring sites. Given the length of the river, ten or more monitoring sites should be implemented for each indicator. We recommend that monitoring sites for channel morphology and large wood be located in the dynamic zones (Figure 1).

Summary of Recommendations

- Monitor up to twelve indicators listed in Table 5, as funding allows.
- Use mapping of active channel boundaries from aerial imagery in GIS as the primary means of monitoring morphological change.
- Conduct a trial of field and imagery mapping of bars to evaluate cost and accuracy before proceeding with bar monitoring.
- Conduct a trial of field and imagery mapping of large wood to evaluate cost and accuracy before proceeding.
- Monitor inundation using a network of recording pressure transducers.
- Monitor secondary channel inlets in the field by topographic survey if time and resources allow.
- Develop detailed written protocols for each monitoring procedure and metadata for each GIS layer created so that future monitoring can be done in a consistent fashion.
- Acquire LIDAR data for the study area floodplain if resources allow.

Table 5. Summary of recommended monitoring indicators and frequencies.

Category	Indicators	Method	Recommended frequency
Main channel morphology	▪ Active channel area ▪ Active channel width	Mapping from imagery	2 to 3 years for the first 10 years; 5 years thereafter
Secondary channel morphology	▪ Active channel length ▪ Active channel area	Mapping from imagery	5 to 10 years; following large flow events
Bars	▪ Area ▪ Frequency (no./km) ▪ Status of individual bars (loss, gain, movement)	Mapping from imagery	2 to 3 years for the first 10 years; 5 years thereafter
	▪ Elevation loss/gain	Field: topo survey, bathymetry	5 years unless other indicators suggest not warranted
Inundation	▪ Inundation stage ▪ Extent (for given flow release)	Gage and piezometer network	Annually or based on flow events
Large wood	▪ Frequency of accumulations (no./km) ▪ Status of individual accumulations (loss, gain, movement)	To be determined: field or imagery	2 to 3 years for the first 10 years; 5 years thereafter

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