PNNL-SA-106864

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

A High-Resolution Area-Time Inundation Index Model (ATIIM) for Restoration Evaluation and Planning under Existing and Alternate Conditions

ANDRE M.COLEMAN[1]

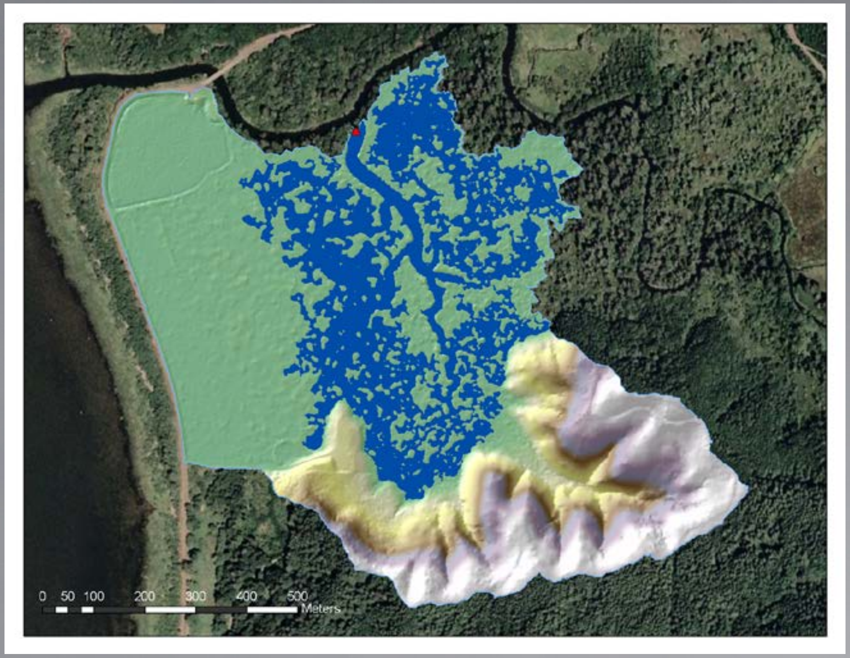
HEIDA L. DIEFENDERFER[2]

CHRIS R. VERNON[3]

AMY B. BORDE[2]

Pacific Northwest National Laboratory
Energy and Environment Directorate

[1] Hydrology Technical Group - Richland, WA
[2] Coastal Ecosystem Research Technical Group - Sequim, WA
[3]Ecology Technical Group – Richland, WA



November 2014 EP Science Work Group Meeting

November 18, 2014

Motivation

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

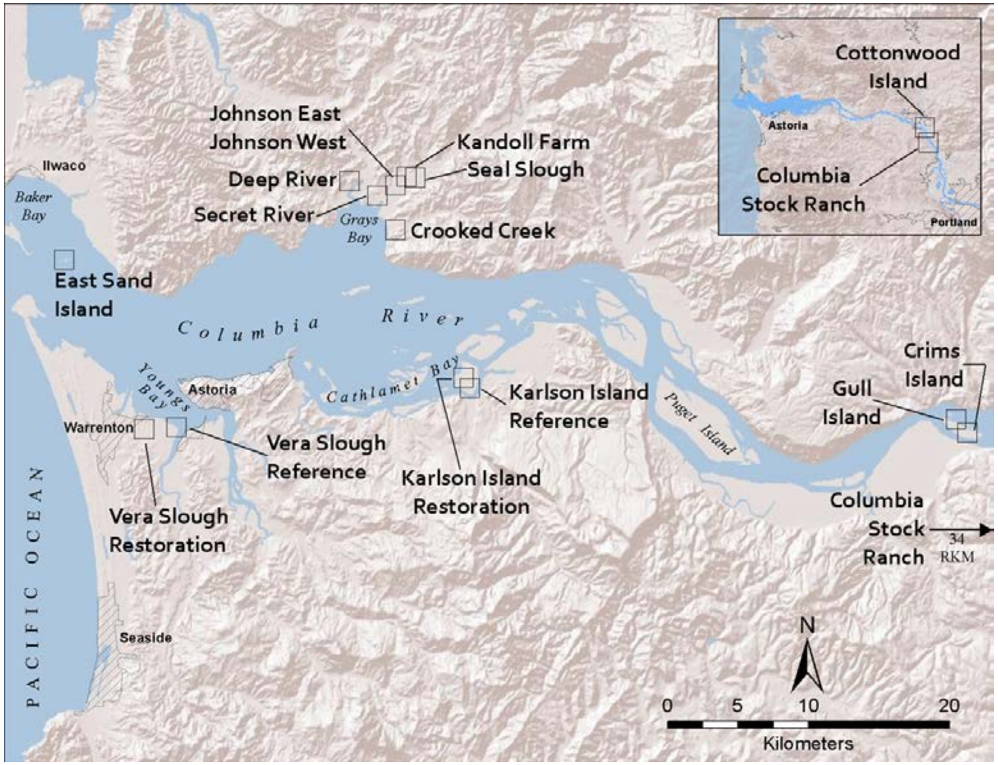
- Corps' CRFM Cumulative Effects Study
  - Recognized the need to measure the wetted habitat area directly available to salmon; as well as the wetland area connected to the main stem Columbia River for indirect food web effects.
- Columbia Estuary Ecosystem Restoration Program (CEERP) Research, Monitoring & Evaluation Plan
  - "Habitat availability is associated with the topography and inundation regime, which in turn are associated with geomorphic features such as the total edge and penetration of tidal channels." (Johnson et al., 2008)

Estuary Expert Regional Technical Group

- *Feedback to Calculator to Assign Survival Benefits Units (SBU)* (doc. ERTG 2011-1) Part 2. “Water Level or Elevation at Which Sub-Action Areas Are Measured”
- Selection of water surface level for estimation of area has a large effect on SBUs; appropriate elevation differs by location; recommends use of the 2-year flood elevation or Extreme Higher High Water (EHHW) (mean highest monthly tide)
- ATIIM Model calculates ERTG-recommended metrics for SBUs, and *12 spatial metrics* and *~40 other metrics* useful for predicting hydrological and biological outcomes

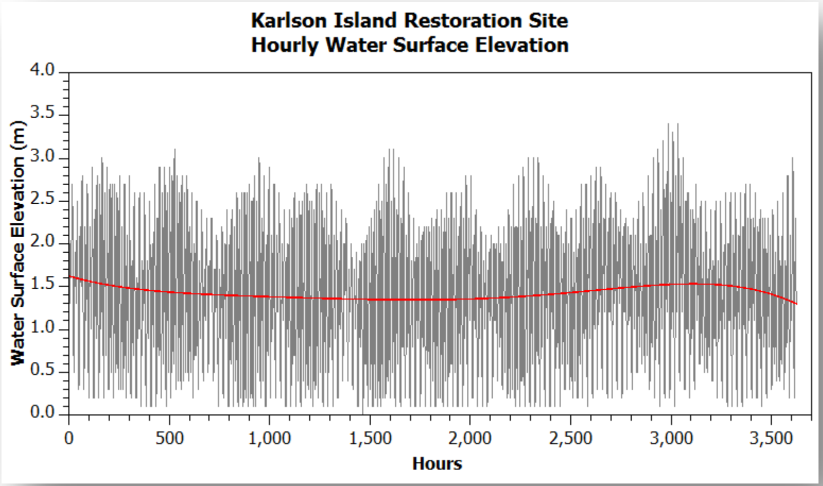
Background

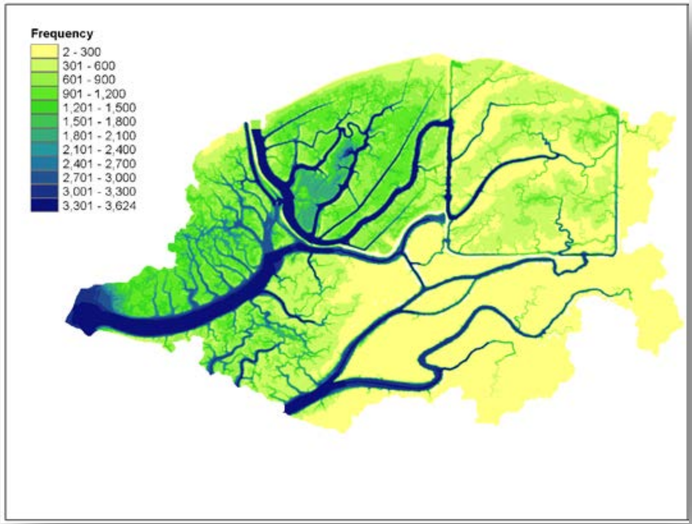
- Model Development
  - Model core developed in 2007 to specifically address a need in the Corps' Cumulative Effects study at several sites including Kandoll Farm and Vera Slough.
- Has been run at ~18 sites in the LCRE
- Model has grown organically as a response to needs



Model Design and Philosophy

- Rapid assessment and feasibility tool for habitat opportunity and capacity
- High spatial resolution (0.5-1m) for site scale assessment
- Focus on physical system and aquatic and terrestrial habitat opportunity components (structure → function)
- Provide the flexibility to evaluate different time scales and compare different site behavior/conditions
- Suitable for both tidal and fluvial dominated sites





Model Design and Philosophy

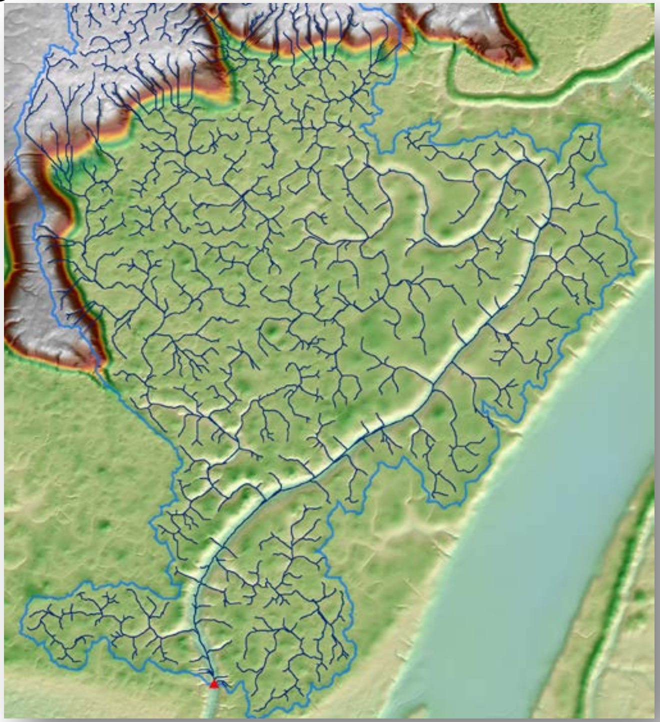
- Adaptable for different types of channel network morphologies
  - Flow-through, bi-directional, multi-directional, multiple inlet/outlets
- Provide data products and metrics not available elsewhere
- Highly customizable
  - Added numerous metrics for calculating avian suitability/disturbance
- Cost-effective screening-level / feasibility study tool
  - Site restoration for fish and avian habitat potential
  - Restoration design alternatives
    - Use in conjunction with, or as a pre-cursor to more intensive hydrodynamics modeling

Model Application

- Inform hydrologic/physical behavior of existing and/or proposed restoration sites

- Determine trade-off space between inundation levels and habitat opportunity and quality

- Compare alternative site restoration designs
  - Dike breach scenarios
  - Terrain modifications
  - Tide gate or culvert modifications



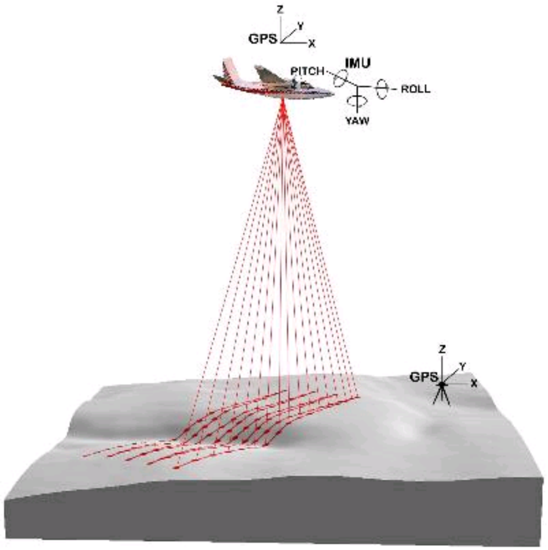
Model Application

- Predict site impacts of altered flow regimes
  - Hydro operations
  - Policy change
  - Climate impacts on flow magnitude/timing/duration
  - Sea level rise
- Aid in determining nutrient and biomass fluxes
  - Flow volume per unit time
- Effectiveness monitoring of changes in the developmental trajectories of restoration sites
  - Adaptive management framework
- Provide standardized site comparisons

Model Overview

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

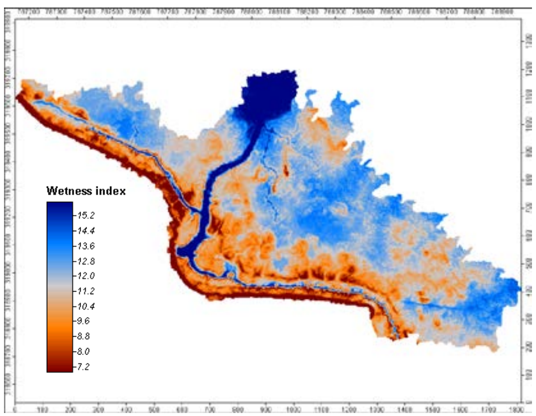
- ATIIM Integrates
  - Advanced terrain processing of high-resolution Light Detection and Ranging (LiDAR) elevation data
  - Available bathymetry data
  - Water surface elevation data
    - In-situ, hydrodynamic, regression-based models, or synthetic
  - An inundated area algorithm that enforces hydrologic connectivity and determines two- and three-dimensional inundation/volume extent over time



Model Overview

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

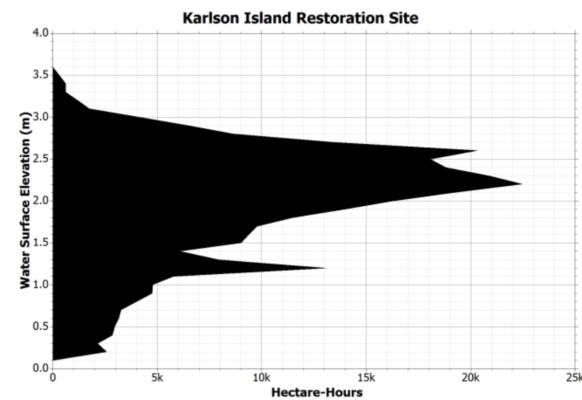
- ATIIM Produces
  - Three general classes of data output



Spatial

.	CC	KI	SS	SR
Time-Steps (hr)	3625	3624	3625	3593
Total Area (ha)	77.6	15	7.9	50
Bankfull Elevation (m, NAVD88)	2.7	2.6	2.5	2.5
% Time of Overbank Inundation	18.7	6.8	14.8	17.4
Total Hectare-Hours	9629	913	1230	7269
Hectare-Hours ≥ Bankfull	8064	607	745	5345
	-83.80%	-66.50%	-60.50%	-73.50%
Hectare Hours < Bankfull	1565	306	486	1924
	-16.30%	-33.50%	-39.50%	-26.50%
Max. Possible Hectare Hour Inundation	140680	27232	14219	89247
Area-Time Index	5.7	2.2	5.2	5.9

Tabular



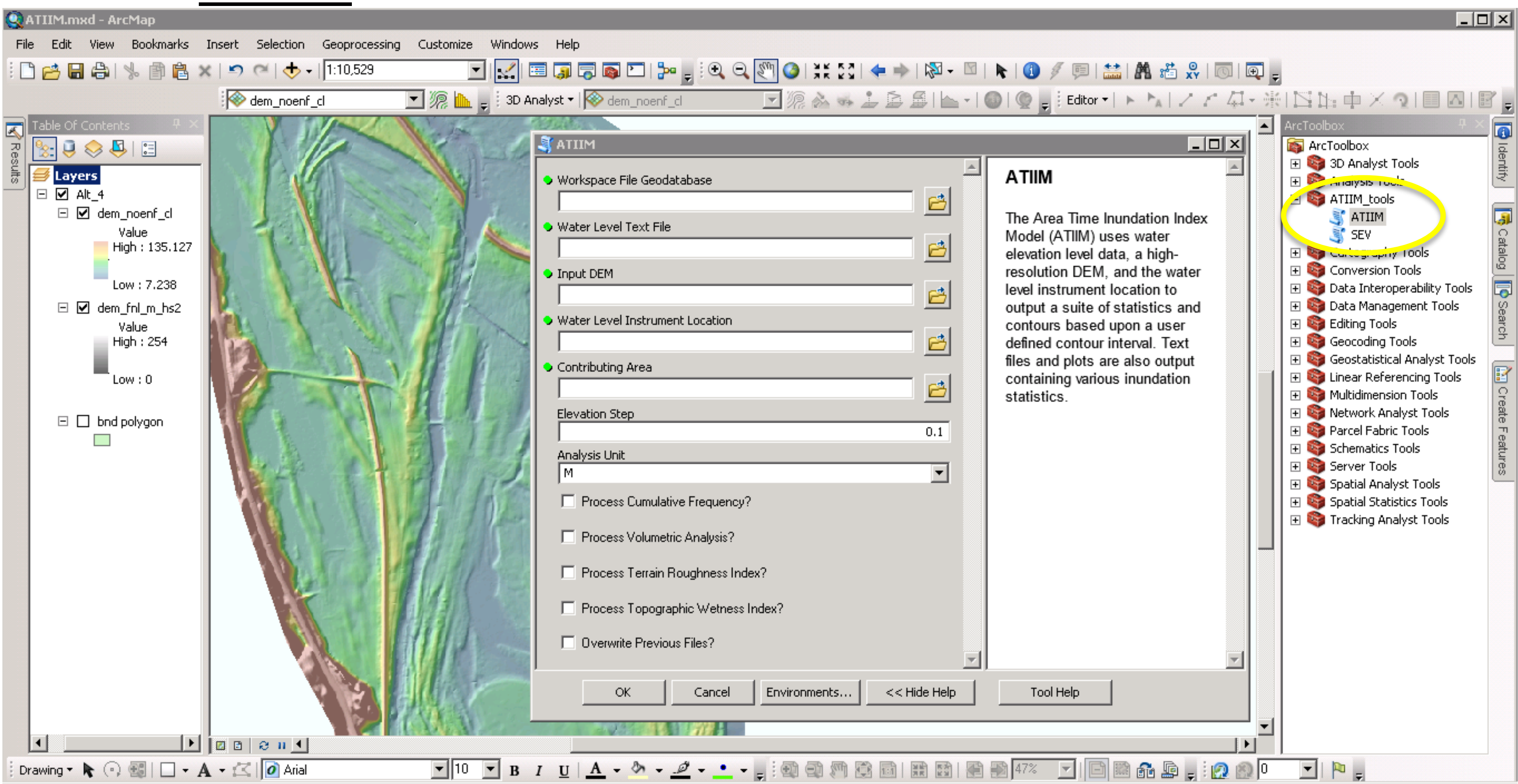
Plots

  - *14 spatial metrics (some varying over time and space)*
  - *49 tabular metrics* useful for predicting hydrological and biological outcomes

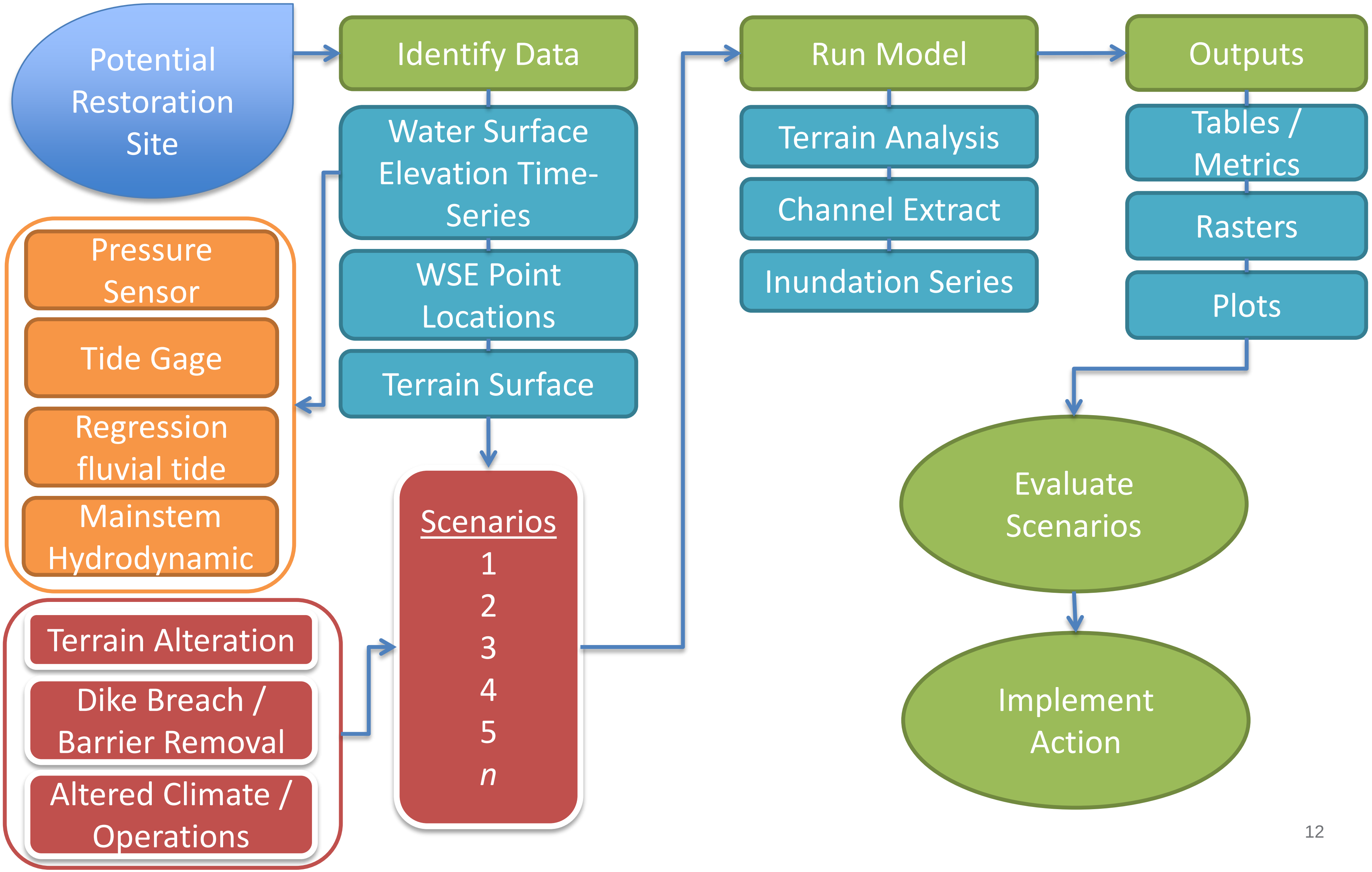
Model Development

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Migration of model to a toolbox module within ArcGIS
  - Objective: <u>Push the toolbox and documentation to the public domain</u>

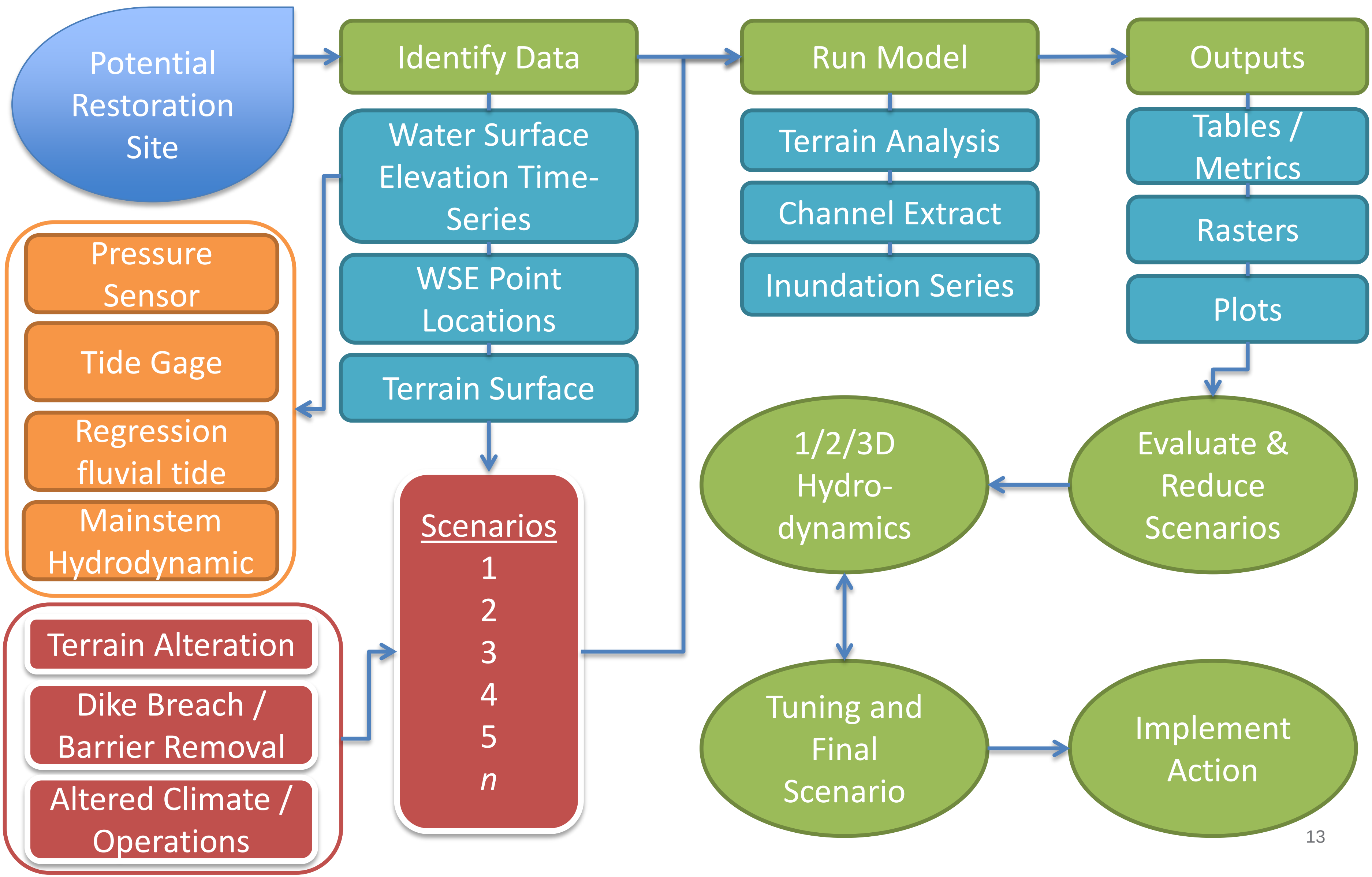


Model Workflow (1)

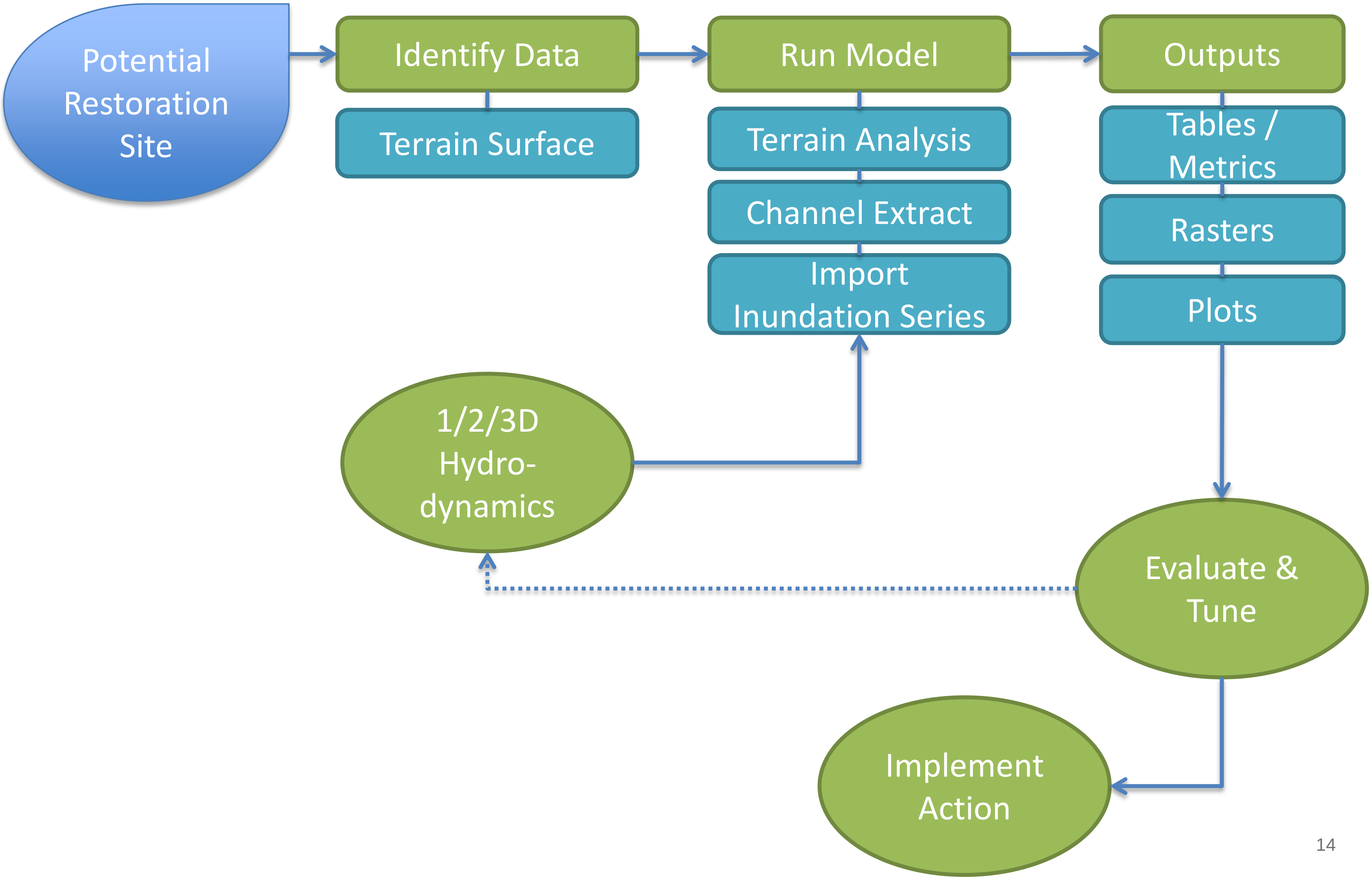


Model Workflow (2)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



Model Workflow (3)

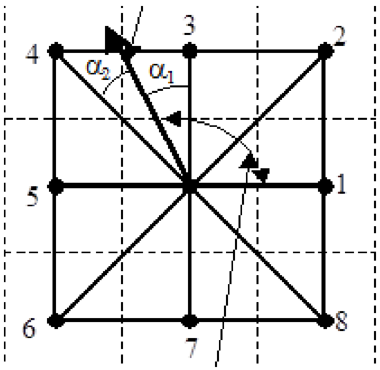


Terrain Analysis

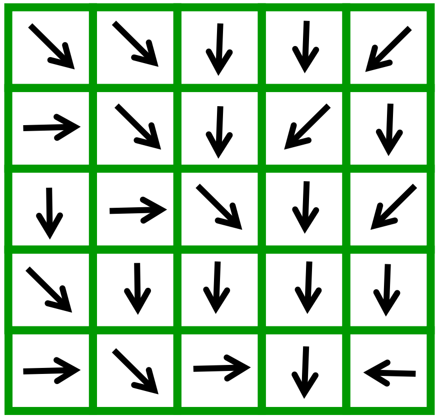
- Terrain Processing
  - Finite-difference, multi-grid, locally adaptive terrain analysis method after Hutchinson (1988, 1989, 1996, 2009)
  - Can use multiple sources of data
    - non-regularly gridded elevation data, contours, xsect
  - Factors in uncertainty in the source data
  - Incorporates profile curvature, planimetric curvature, and total curvature as terrain roughness penalties
    - Provides for a realistic terrain surface honoring principles of morphometry and hydrologic flow
    - Highly effective for processing complex, high-density, low-relief terrain → reveals microtopography

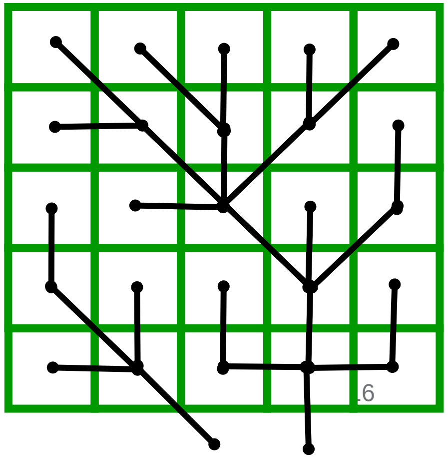
Terrain Analysis

- Deterministic Infinity Method (D∞) (Tarboton 1997)
  - Produces flow direction, flow accumulation, flow paths, and upslope contributing area
  - Elevations of surrounding 8-cells determined
  - Cells split into planar triangular facets
  - Direction of steepest descent determined
  - Very effective for use in low-relief areas



- Deterministic-8 Method
  - Most common method
  - Not sensitive enough

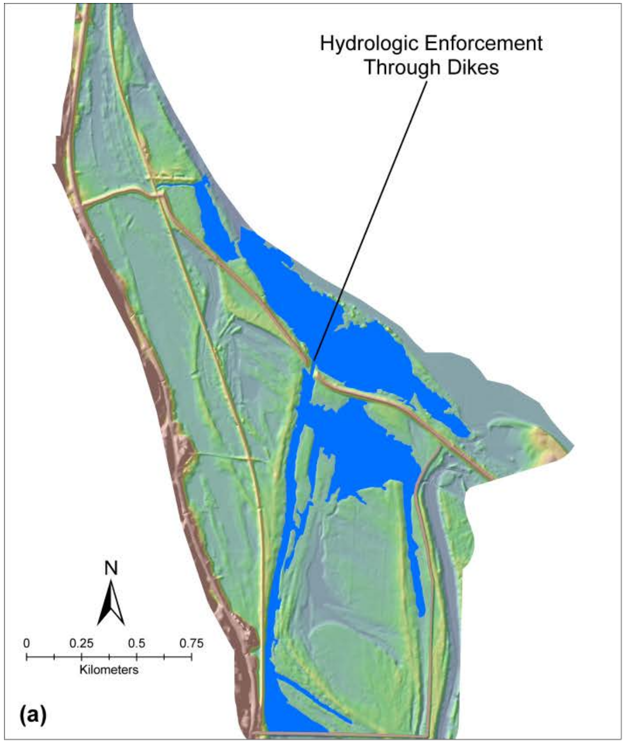


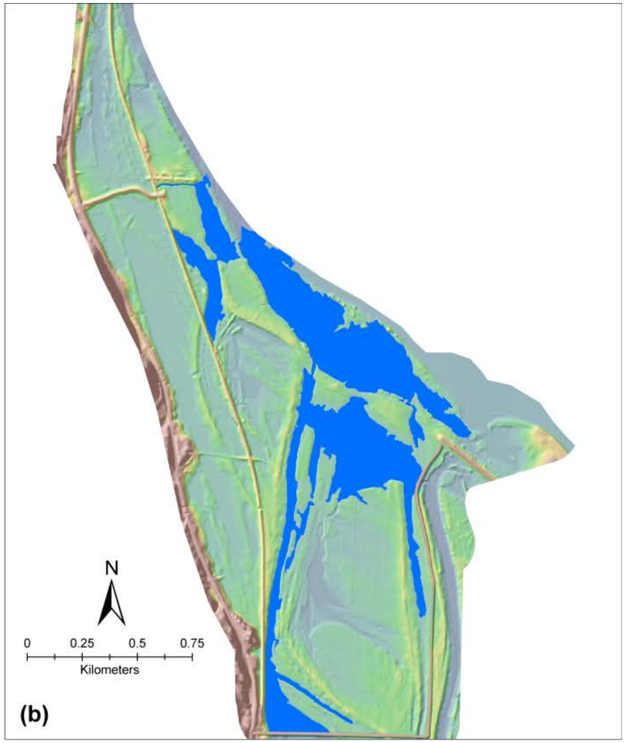


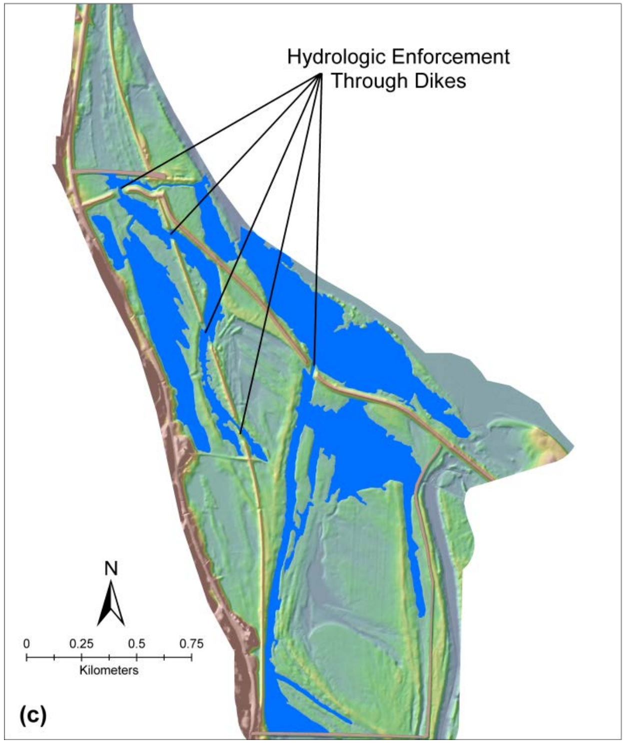
- Inundation Slices
  - Region growing algorithm
    - Remote-sensing/image processing based method for classification/image segmentation
    - Uses kernel/seed point (WSE sensor) to grow from
    - Criterion:
      - Must always proceed in direction of flow
      - Cannot proceed past defined catchment boundary
      - Must honor matrix Z values and not exceed current process-step WSE value
    - To grow from kernel, evaluation of adjacent model cells takes place, those that meet the criterion are added to the cluster
    - Method enforces hydrologic connectivity from the kernel
    - Area and volume of the inundation slice is calculated and stored

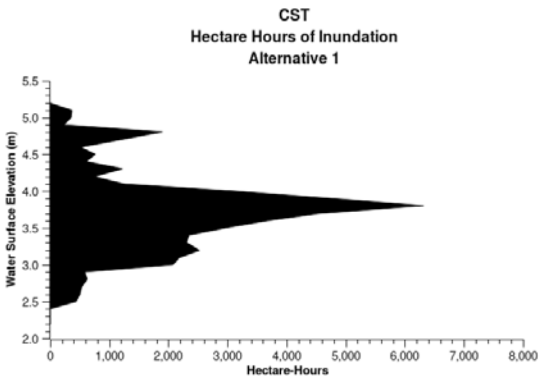
Alternative Design Scenarios

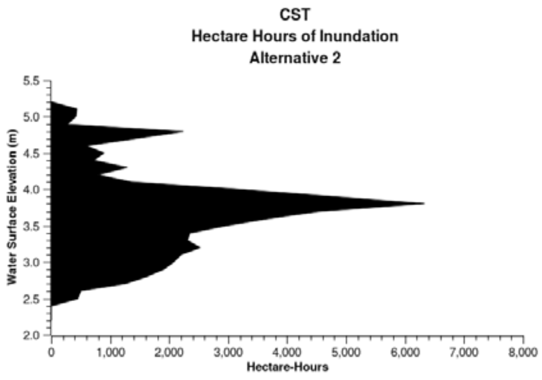
- Columbia Stock Ranch (WSE = 4.1m)

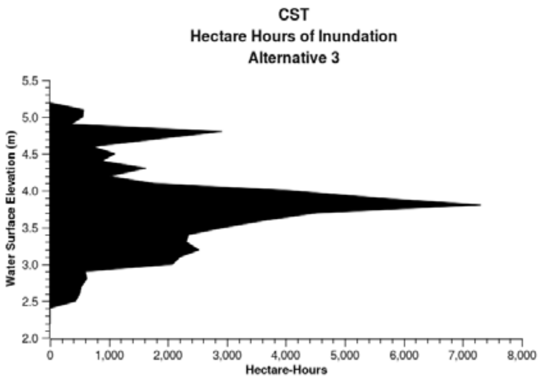






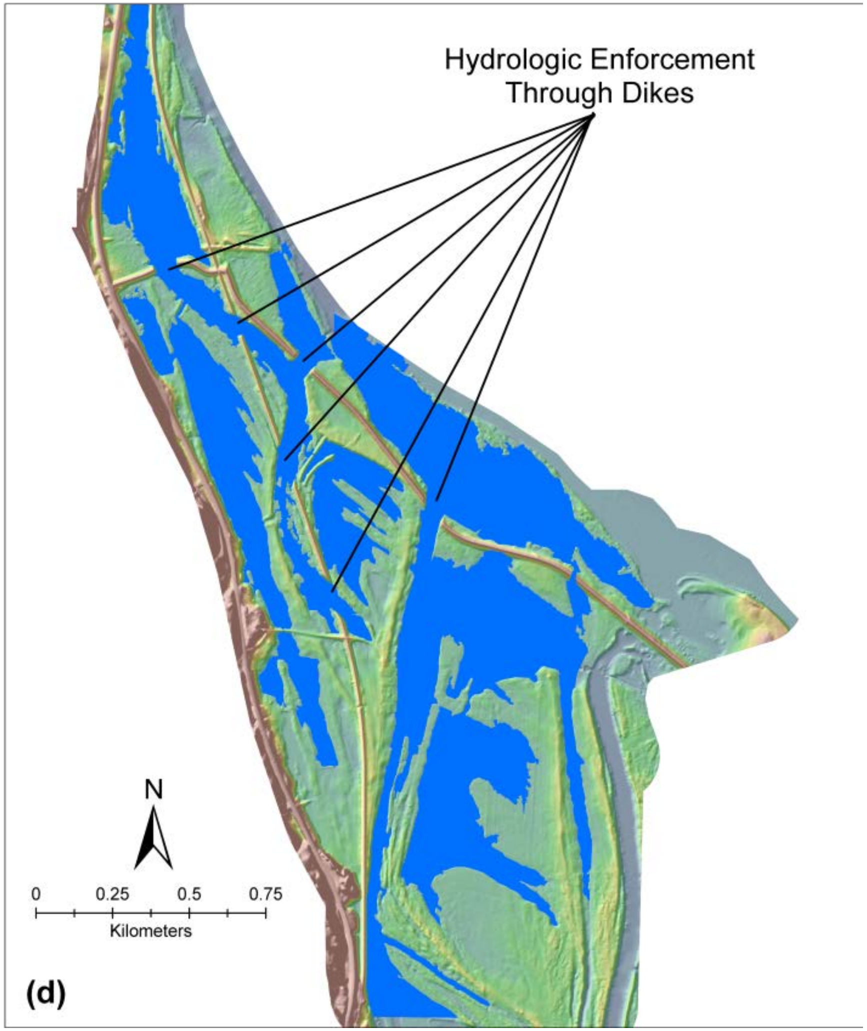


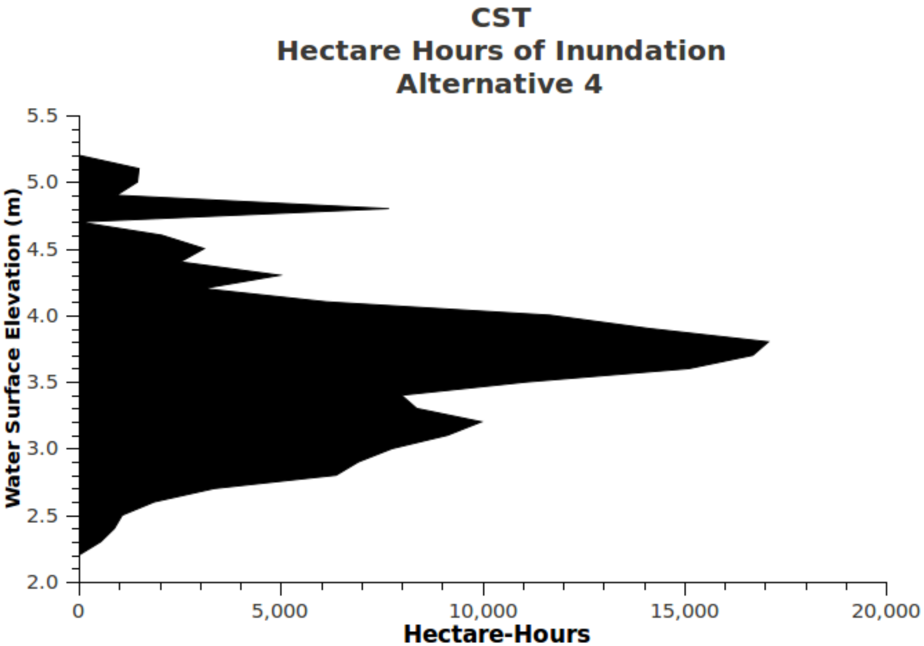




Alternative Design Scenarios

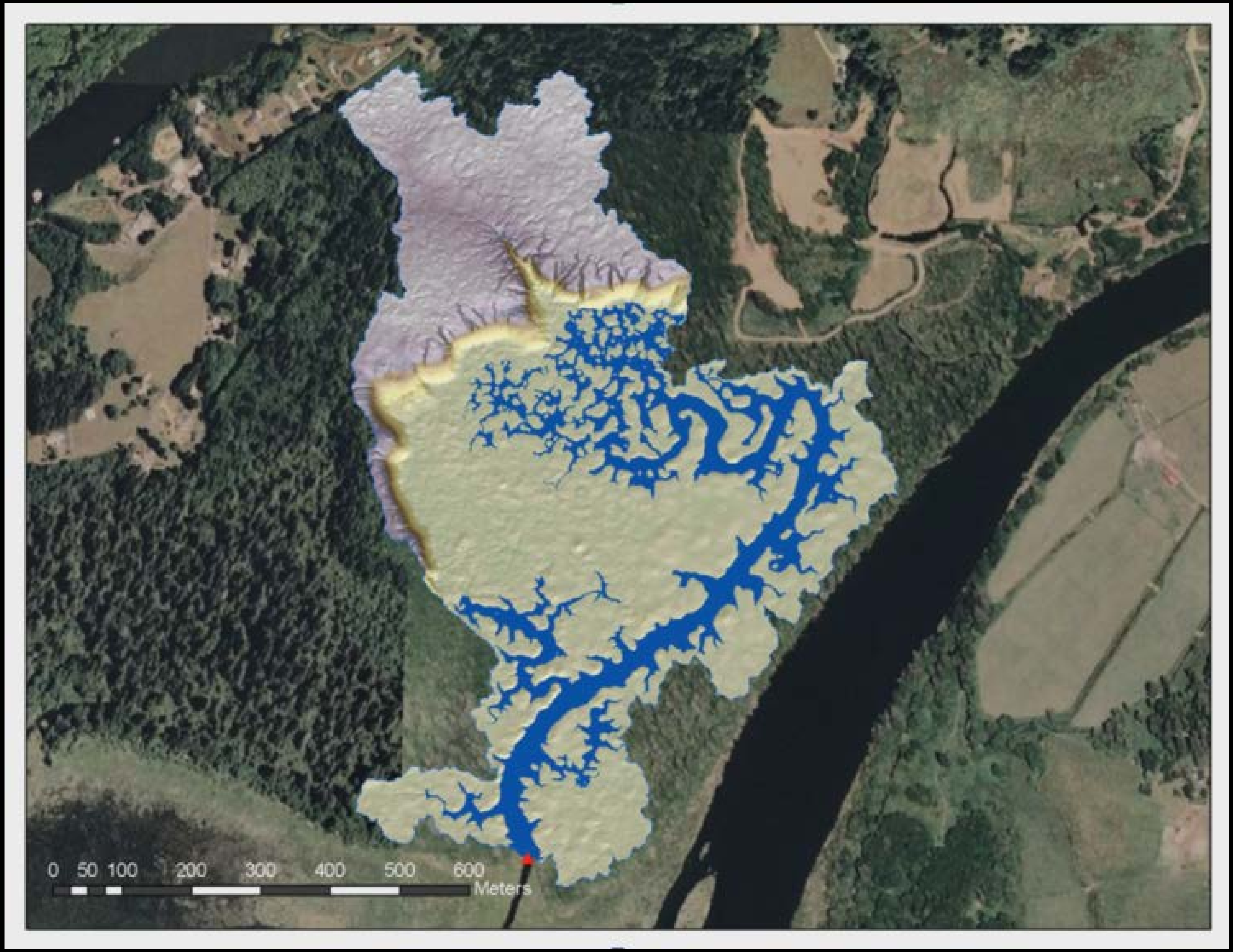
- Columbia Stock Ranch (WSE = 4.1m)





- Minimal differences between alternatives 1-3
- Alt 4 came later as a result of findings from Alts 1-3 and met restoration planning objectives

Inundated Area

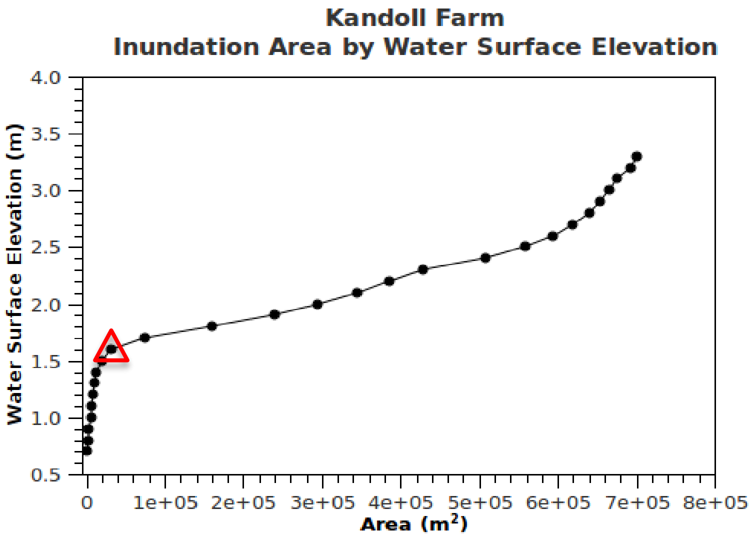


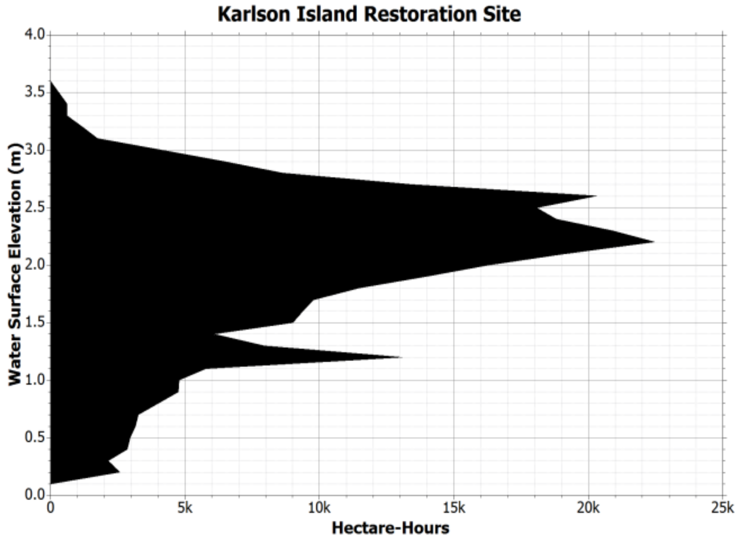
Inundated Area

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Example Outputs

- **Elevation/Area Relationship**
- **Bankfull Elevation**
- **Percent Time of Overbank Inundation**
- **Total Hectare Hours:** The total number of hectares inundated at each time and elevation-step through the study period.

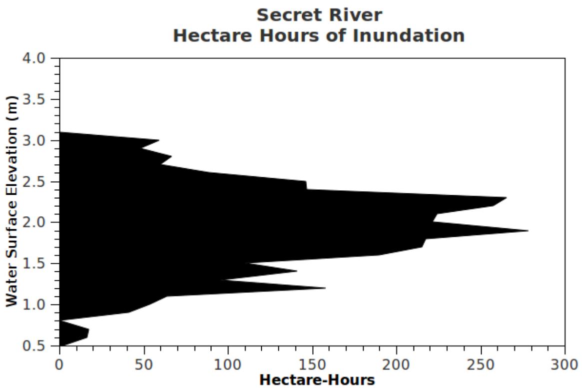


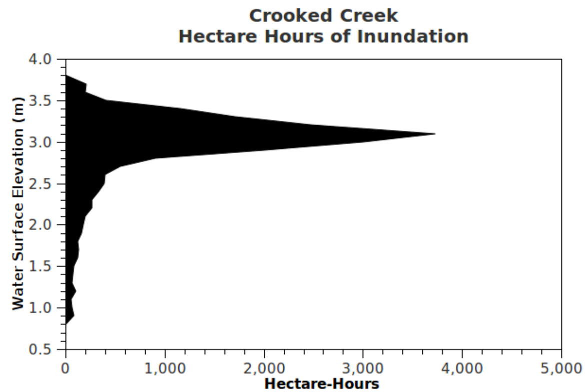


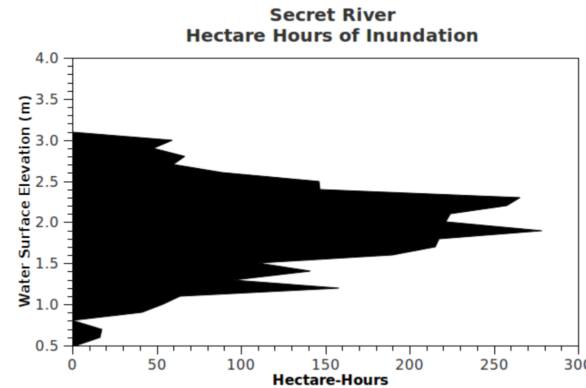
Example Outputs

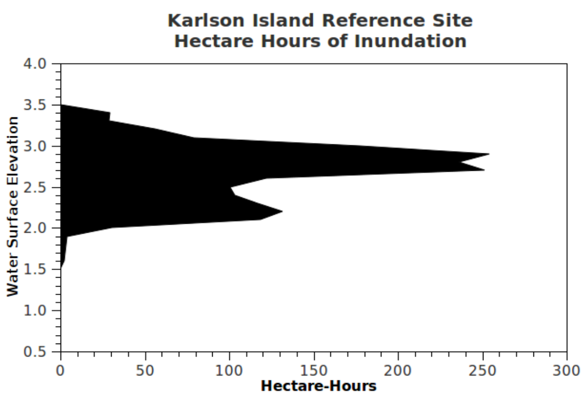
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

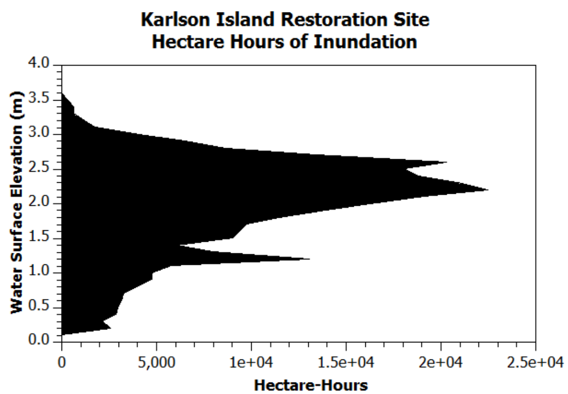
- Hectare-Hours of Inundation

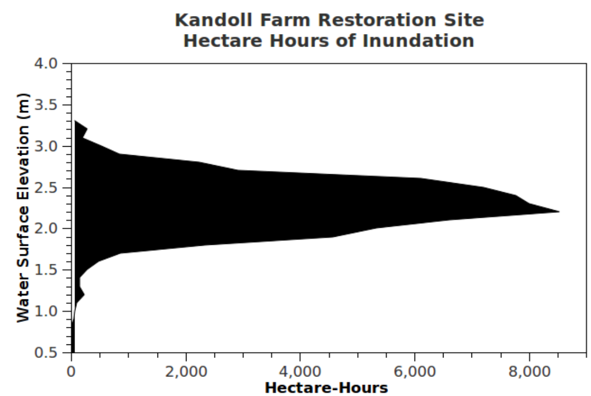




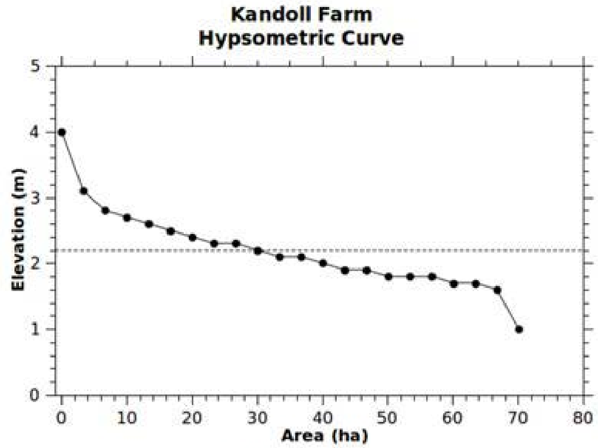


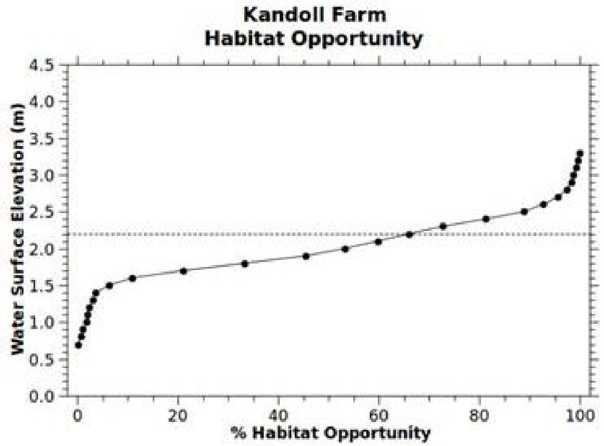


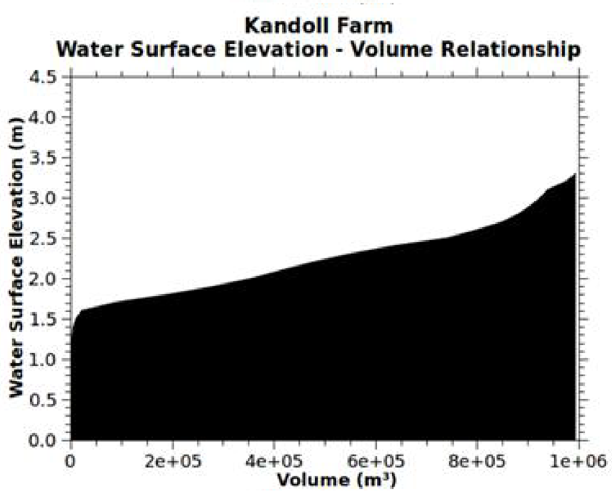


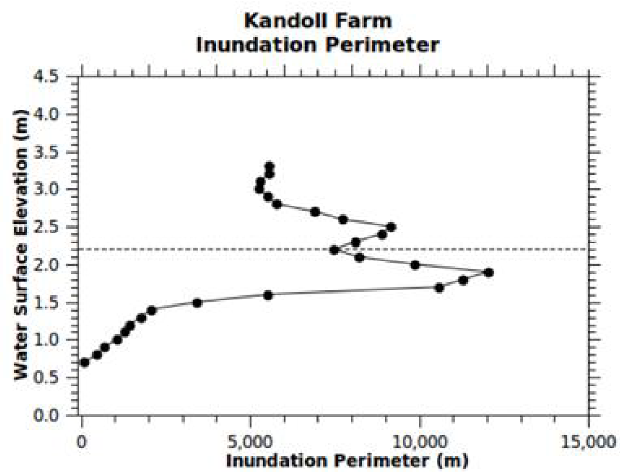


Example Graph Outputs







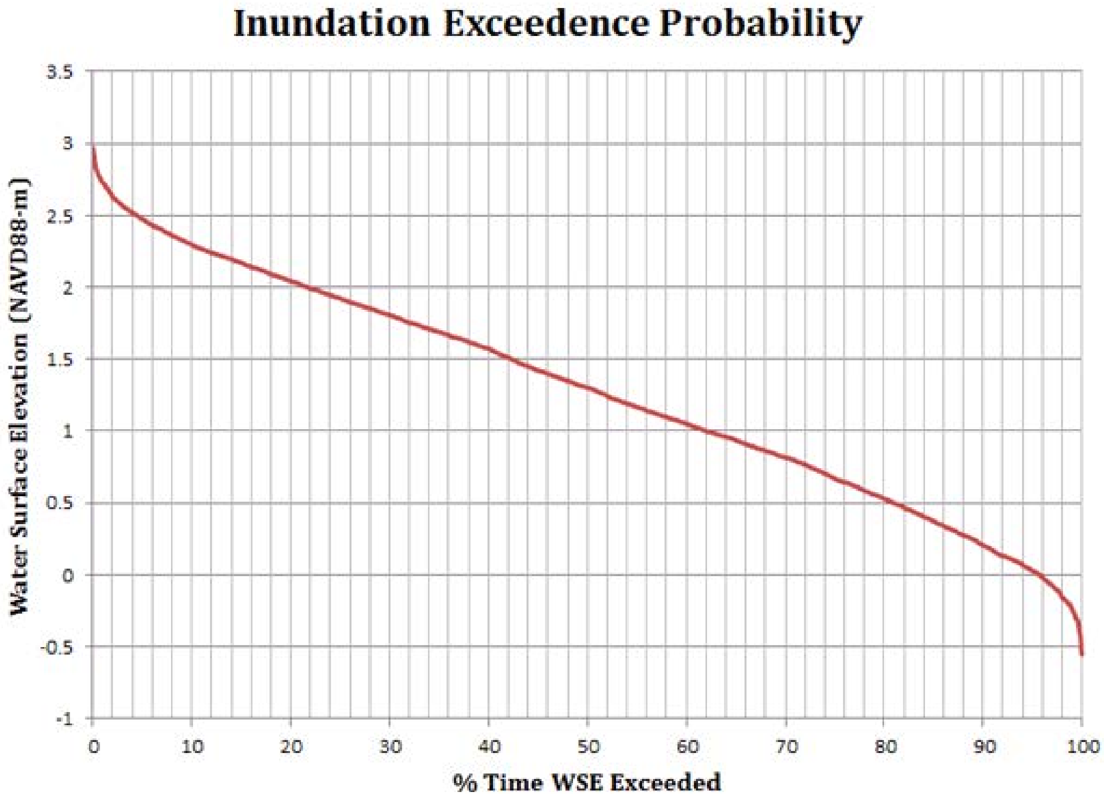


Example Graph Outputs

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

- **Inundation Exceedence Probability**:
  A measure to indicate the probability of occurrence (based on the historical record) for a specific elevation to be inundated. A value of 99% would indicate that the particular elevation is inundated often (lower elevations) and a value of 1% would indicate rare occurrences of inundation (high elevations).



Sum Exceedence Value (SEV)

- ATIIM-SEV analysis to estimate major plant communities (Borde et. al)
  - SEV metric is based on patterns of inundation during vegetation growing season
  - Project the future potential vegetation distribution under altered climate / sea-level rise scenarios

Current & Future Work

- Efforts underway to migrate current model into ArcGIS framework
  - Provides a user-friendly and familiar interface
  - Couple with other existing capabilities within ArcGIS
  - Ability to link data to network geodatabases and/or web-based data services
  - Requires linking specialized terrain-processing and hydrologic extraction codes into ArcGIS
  - Incorporating programmable plotting packages that can read from a geodatabase
- Make this tool publically available without cost

Peer-Reviewed Publications

Diefenderfer, HL, AM Coleman, AB Borde, IA Sinks. 2008. Hydraulic geometry and microtopography of tidal freshwater forested wetlands and implications for restoration, Columbia River, U.S.A., *Ecohydrology and Hydrobiology,* 8(2-4), pp. 339-361.

Coleman, AM, HL Diefenderfer, DL Ward, AB Borde. Spatially Based Area-Time Inundation Index Model Developed to Assess Habitat Opportunity in Tidal Wetlands and Restoration Sites*, Ecological Engineering, in review*.

Acknowledgements

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- **U.S. Army Corps of Engineers – Portland District**
  - Blaine Ebberts
  - Cindy Studebaker
- **Columbia Land Trust**
  - Scott McEwen
  - Ian Sinks
- **NOAA – Northwest Fisheries Science Center**
  - Curtis Roegner
- **PNNL**
  - Gary Johnson
  - Ron Thom
  - Shon Zimmerman
  - Ron Kauffman

US Army Corps of Engineers ®
Portland District

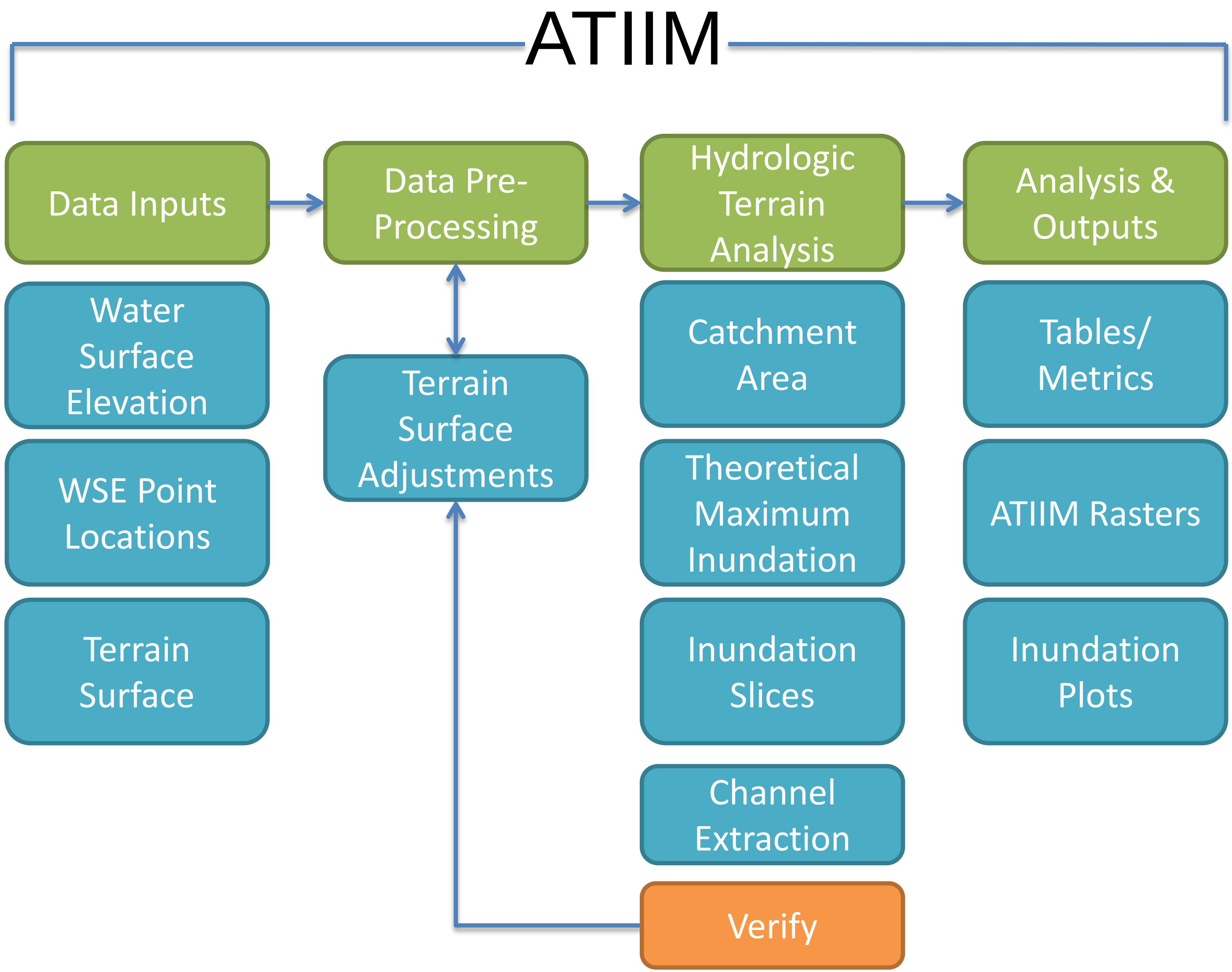
Columbia LAND TRUST

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NOAA U.S. DEPARTMENT OF COMMERCE

NOAA FISHERIES

Backup Slides

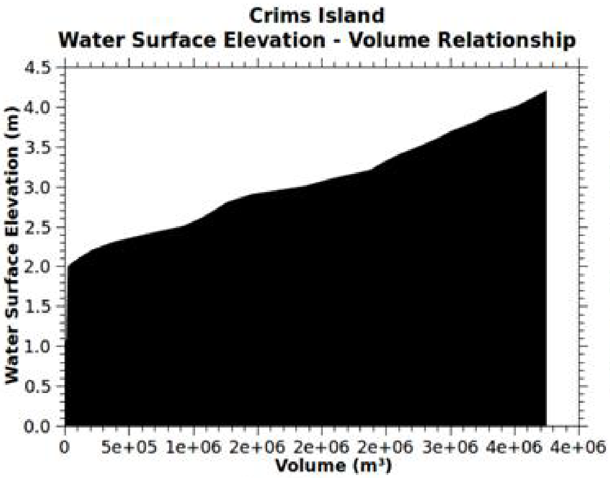
Model Workflow

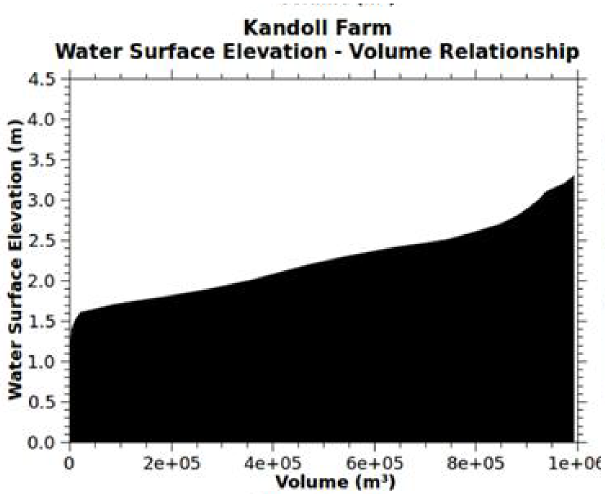


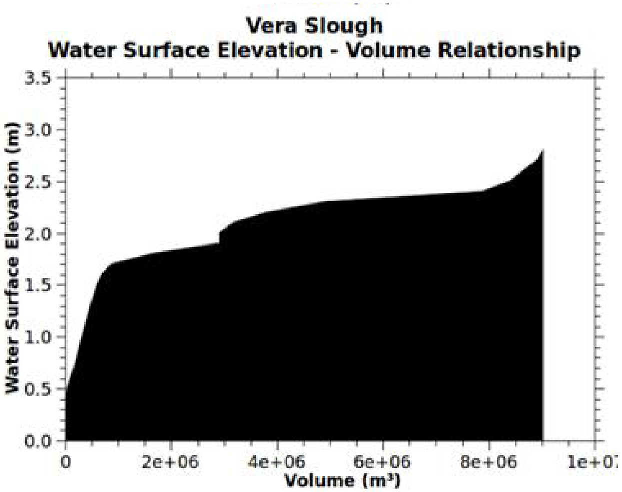
Tidal Exchange Volume Metrics

- **Time Volume Inundation Index:** The percent time of volumetric inundation is calculated as the actual volume of water, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum acre-feet-hours for the site.

- **Surface-Area to Volume Ratio:** Ratio of the planimetric surface area to the three-dimensional volume at each 10-cm increment of elevation.







Additional Inundation Metrics

- **Maximum Water Surface Elevation Frequency (MFWSE):** Most frequently observed water surface elevation in the period of record.
- **Habitat Opportunity at MFWSE:** The habitat opportunity percentage and length at the most frequently observed water surface elevation in the period of record.
- **Inundation Perimeter:** Data series of the total perimeter length of inundated area at each 10-cm increment in the WSE data record. This measure of the aquatic-terrestrial interface provides information about site characteristics and the potential for habitat opportunity and nutrient/biomass flux.
- **Inundation Perimeter at MFWSE:** The inundation perimeter length at the most frequently observed water surface elevation in the period of record.
- **Water Surface Elevation Percent Frequency at Bankfull Elevation:** WSE frequencies greater than or equal the mean bankfull elevation provides an indicator of the potential frequency that fish could access the marsh edge for feeding.
- **Total Site Channel Density:** Stream channel length per unit area calculated by dividing the total center-of-channel length at the site by the total site area.
- **Inundated Channel Density:** Stream channel length per unit area calculated at each 10-cm increment of elevation providing a measure of density in the aquatic/terrestrial interface over varying tidal/flow levels.

Example Aquatic Habitat Metrics

- **Drainage density**: Stream length per unit area (total channel length/catchment area) (Horton 1932)
- **Drainage density at each inundation level**: Measure of density in the aquatic/terrestrial interface over varying tidal/flow levels
- **Total channel edge length**: Captures the total potential habitat opportunity on either side of the channel
- **Total channel edge length at each inundation level**: Measure of total potential habitat opportunity with varying tidal/flow levels
- **Habitat Opportunity Metric**: Determines the percent of total access opportunity, by summing the length of inundated channels at a given WSE and dividing by the sum of channel length for the entire site

Example Terrestrial Habitat Availability Metrics

- **Cumulative Frequency of Inundation**: This metric describes how often, on the basis of percent of total possible time, a specific elevation has been inundated over the study period.

- **Total Non-Inundated Hectare-Hours**: The sum of the total number of hectares at a site that are not inundated (i.e., dry areas) at each hourly time-step over the study period.
  - User-defined study period – 24 hours/day
  - Dry hectare hours at night per week

- **Longest Duration of Non-Inundation**: The longest period of time, in hours, that a specific elevation did not get inundated with a minimum 0.2 m water depth.
  - Evaluate at user-defined time-periods, i.e., weekly, monthly

Example Terrestrial Habitat Availability Metrics

- **Mean Site Inundation Depth**: The average water depth for the site at a given water surface elevation.
- **Functional Hectares Excluded**: This is a general metric to understand how water inundation would affect nesting/foraging locations.
- **Sum Exceedence Value**: Cumulative sum of the difference between hourly water surface elevation and land surface elevation during the growing season. Used as an indicator for vegetation communities.

ATIIM Metrics

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Data group	Data	Description
Spatial Data Sets	Surface	Processed and merged LiDAR and bathymetry data with channel enforcement (where LiDAR elevation missing due to standing water at the time of data collection)
	Flow Accumulation	Raster-based microtopographic flow accumulation for channel routing
	Flow Direction	Raster-based microtopographic flow direction for channel routing
	Channels	Microtopographic channel network
	Flow Path Length	Vector and raster microtopographic channel length
	Channel Distance	Raster-based horizontal and vertical distance to defined channels
	Boundaries	Site drainage boundary and sub-basins within primary site
	Inundation	Data series of two-dimensional wetted area inundation polygons at 10-cm increments through the minimum/maximum range of the water-surface elevation record
	Cumulative Frequency of Inundation	Raster-based normalized frequency of inundation
	Volume	Data series of three-dimensional volumetric area inundation at 10-cm increments through the min/max range of water-surface elevation record (provides basis for calculating nutrient fluxes in the tidal exchange)
	Roughness	Raster-based Terrain Ruggedness Index (index can be used as a metric for restoration progress and habitat opportunity)
	Steady-State Modified Topographic Wetness Index	Raster-based steady-state modified topographic wetness index (index can be used to determine high soil-saturation zones and existing/potential restoration wetlands based on natural topography)

ATIIM Metrics

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Data group	Data	Description
NEW	Quasi-Dynamic Topographic Wetness Index	NOTE: Still in development. Requires soils and land cover data, hourly precip (or disaggregated daily totals).
NEW	Water Depth	Water depth at each WSE layer. Will be the difference between current WSE minus the DEM elevation Min/Max/SD
NEW	SEV	Sum Exceedence Values for the site (Borde et al.) – Used to understand potential vegetation community establishment.
Tabular Metrics	Total Time Steps	The total number of hourly time-steps used in the analysis; this value is based on the length of record available from observed water-surface elevations
	Days Verification	Number of days used in the analysis
	Auto-Determined Site Bankfull Elevation	Using an automated graph-based slope-change algorithm, the site average bankfull elevation is determined **Include this value as a separate line in the output file.
	Time Steps < Inundation Elevation of X	The number of time-steps where water exists below the bankfull elevation (X)
	Time Steps >= Inundation Elevation of X	The number of time-steps where water exists at or above the bankfull elevation (X)
	Percent Time of Overbank Inundation	The percent time (from the total time-series) where water is at or above the bankfull elevation
	Total Site Area	The total drainage area of the site
	Total Area-Hectares	Total drainage area of the site measured in hectares
	Total Inundated Hectare Hours	The total number of hectares inundated at each time-step through the study period. Evaluation of inundation is occurring at 10 cm increments of elevation.

ATIIM Metrics

Data group	Data	Description
	Hectare Hours < X	The number of hectare-hours below the bankfull elevation (X)
	Percent Hectare Hours < X	The percent (from the total time-series) of hectare-hours below the bankfull elevation
	Hectare Hours >= X	The number of hectare-hours at or above the bankfull elevation (X)
	Percent Hectare Hours >= X	The percent (from the total time-series) of hectare-hours at or above the bankfull elevation
	Theoretical Maximum Hectare Hour Inundation	The theoretical maximum hectare-hour value at the site, assuming the entire site is inundated for the entire time-series **USES FULL BASIN AREA
	+2SD Hectare Hour Inundation	The hectare-hour value at the site, assuming the site is inundated to a water surface elevation at 2 standard deviations above values in supplied WSE record.
	Area-Time Inundation Index – Theoretical	The percent time inundation, or area-time inundation index, is calculated as the number of hectare-hours of inundation, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum hectare-hours for the site
	Area-Time Inundation Index (+2SD)	The percent time inundation, or area-time inundation index, is calculated as the number of hectare-hours of inundation, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum hectare-hours for the site
	Volume-Time Inundation Index – Theoretical	The percent time of volumetric inundation is calculated as the volume of water, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum acre-feet-hours for the site

ATIIM Metrics

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Data group	Data	Description
	Volume-Time Inundation Index (+2SD)	The percent time of volumetric inundation is calculated as the volume of water, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum acre-feet-hours for the site
	Surface Area to Volume Ratio	Ratio of the planimetric surface area to the three-dimensional volume at each 10-cm increment of elevation
	Maximum Frequency Water-Surface Elevation (MFWSE)	Most frequently observed water-surface elevation in the period of record ** NOTE: For plots where there is a Y-Axis showing Elevation/WSE, include a dashed horizontal line to represent the WFWSE elevation.
	Habitat Opportunity	Data-series of channel-edge length based habitat availability at 10-cm increments of elevation
	Percent Habitat Opportunity	Data-series of percent habitat availability at each 10-cm increment divided by the total possible habitat availability
	Habitat Opportunity at MFWSE	The habitat opportunity percentage at the most frequently observed water-surface elevation in the period of record
	Water-Surface Elevation Percent Frequency at Bankfull Elevation	WSE frequencies greater than or equal to the mean bankfull elevation (can be used as an indicator of the potential frequency that fish could access the marsh edge for feeding)
	Total Site Channel Density	Stream channel length per unit area calculated by dividing the total center-of-channel length at the site by the total site area

ATIIM Metrics

Data group	Data	Description
	Inundated Channel Density	Stream channel length per unit area calculated at each 10-cm increment of elevation providing a measure of density in the aquatic/terrestrial interface over varying tidal/flow levels
	Inundation Perimeter	Data series of the total perimeter length of inundated area at each 10-cm increment in the WSE data record. This measure of the aquatic-terrestrial interface provides information about site characteristics and the potential for habitat opportunity and nutrient/biomass flux. ** This is currently included as a plot and text dump file. Maybe change name of dump file to "Inundation_Area_Perimeter_output.txt"
	Inundation Perimeter at MFWSE	The inundation perimeter length at the most frequently observed water-surface elevation in the period of record
	Elevation-Area Relationship (Hypsometric Curve)	Assessment metric of the landform shape at a site (provides basic metric of opportunity for inundation and habitat opportunity) **Outputs to "Hypsometric_Curve_output.txt" Auto-generate plot from this data.
	Site Mean Terrain Ruggedness Index	See description under Spatial Data Sets. ZONALSTATS for entire site
	Site Standard Deviation Terrain Ruggedness Index	See description under Spatial Data Sets. ZONALSTATS for entire site
NEW	Mean +SD Terrain Ruggedness Index by WSE	Zonal stats – mean and SD TRI for each WSE band. Dump to a separate output table, "Mean_Terrain_Ruggedness_Index_output.txt". We will also generate a plot of mean data, WSE on Y-Axis, Mean TRI value on X-Axis. I expect this will look a bit like the inundation perimeter plot. *For specific band*

ATIIM Metrics

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Data group	Data	Description
	Site Mean Topographic Wetness Index by WSE	See description under Spatial Data Sets.
	Site Standard Deviation Wetness Index by WSE	See description under Spatial Data Sets.
NEW	Mean + SD Depth by WSE	Zonal stats – mean and SD water depth for each WSE elevation this would include an area from current WSE all the way down to the minimum WSE and not just the elevation band. **NOTE: Dumps to a separate output table, "Mean_Depth_output.txt". Auto- generate a plot of this data, WSE on Y-Axis, Mean Depth value on X-Axis.
NEW	Inundation Exceedence Probability	Measure to indicate probability of occurrence of individual WSE's based on study period of observed/modeled WSE's. NOTE: Produces a table, "Inundation_Exceedence_Probability_output.txt" and a complementing plot with WSE on Y-Axis and Probability on X-Axis.
NEW	Min/Max WSE Elevations	Minimum and maximum WSE values in period of record.
NEW	Min/Max Site Elevation	Minimum and maximum elevation values
NEW	Total Dry Hectare Hours	The total number of hectares that remained dry (non-inundated) at each time-step through the study period.
NEW	Total Area above Maximum WSE	The total area, in square meters, of the study site that is above the maximum recorded WSE for the study period.
NEW	% Area above Maximum WSE	The percent area of the study that is above the maximum recorded WSE.

ATIIM Metrics

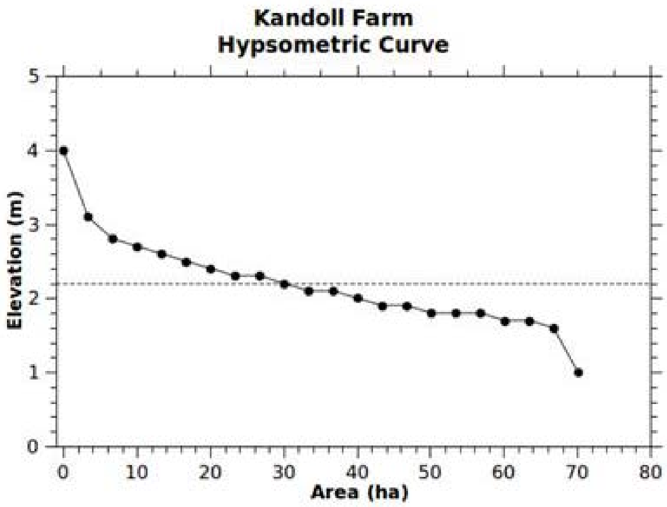
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

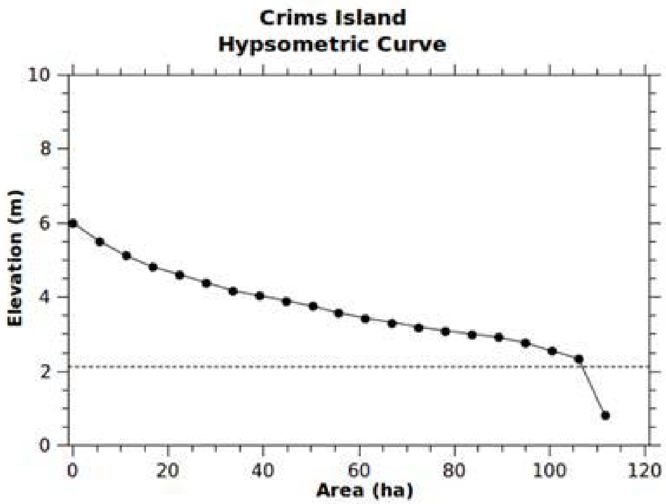
Data group	Data	Description
NEW	Total Dry Hectare Hours Above Maximum WSE	The total numer of dry hectares above the maximum WSE at each time-step through the study period. This is the total areas
NEW	Dry Hectare Hours by Elevation	Produces a table identical to 'frequency_output.txt', but is for non-inundated land. Calculates additional elevation polygons at 10cm increments up to the maximum elevation of the site. NOTE: Produce auto-generated plots similar to 'hectare hours of inundation' but is 'Dry Hectare Hours'.
NEW	Dry Area by Elevation	This produces a table similar to 'InundationArea_output.txt', but is dry area by elevation instead.
NEW	Inundation Events per Week	Evaluation of areas inundated >= 6" depth (WSE – LiDAR Elev) -Calculate average depth for each elevation slice -Calc number of inundation events for each slice down to minimum WSE (aggregated slice) per week and dumps to a table for XY plot.
NEW	Dry Hectare Hours at Night per Week	Dry Area exposed during the night per week (for Brown Pelican) -Collecting hectare-hours per week and generating an XY plot (x-axis week #, y-axis = hectare hour value) -Includes solar code to identify daily sun down and sun up to define these bounds for each location.

Topographic Landform Analysis

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

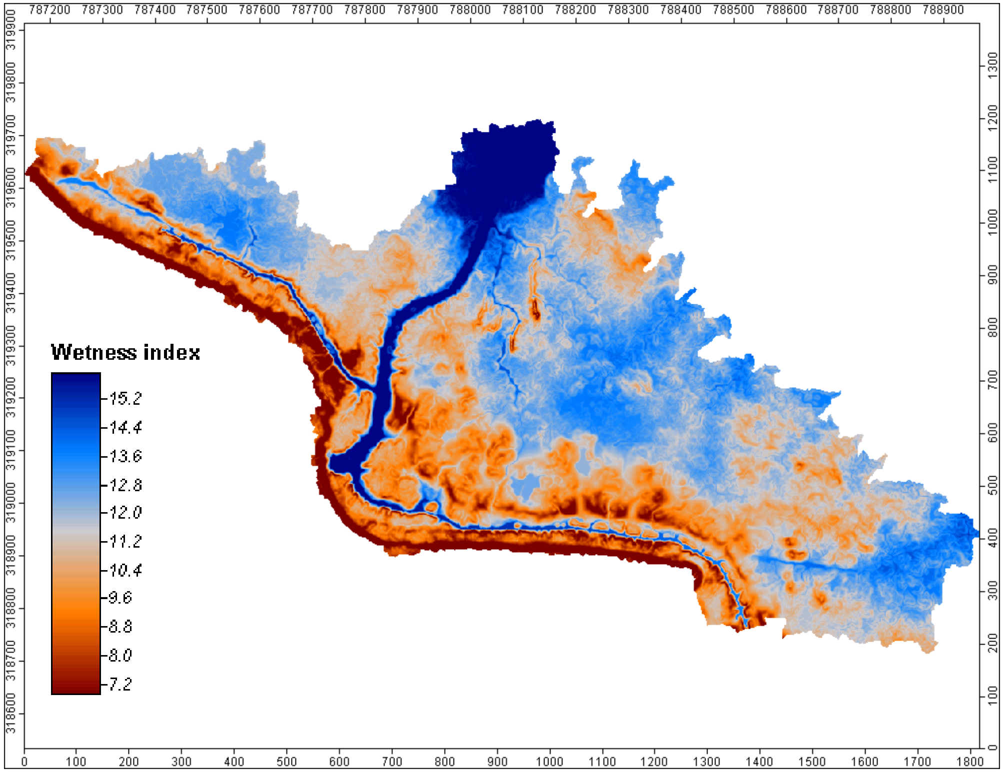
- Site Hypsometry
  - Hypsometric curve (Harlin 1978)
    - Cumulative probability distribution that captures the elevation-area relationship of an area.
  - Captures general topographic landform
  - Quick assessment of site
    - Opportunity for inundation and habitat opportunity





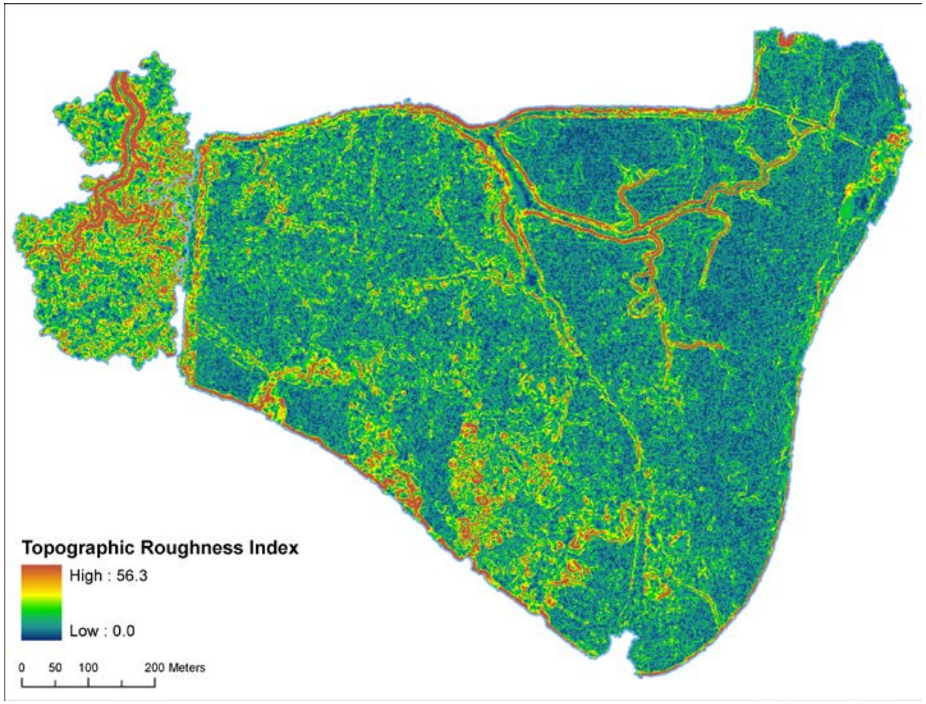
ATIIM Raster Outputs

- Modified Topographic Wetness Index (Boehner et al. 2002)
- The modified topographic wetness index (MTWI) estimates a spatially distributed steady-state condition of soil saturation and, ultimately, runoff generation.
- The MTWI can provide value in determining existing and potential restoration wetlands based on natural topography.
  - Combined MTWI with newly developed rule-based object-oriented classification methods of remote-sensing data has been applied in non-estuarine wetland mapping programs with a high-degree of success (Coleman 2010).



ATIIM Raster Outputs

- Topographic Roughness Index (Riley et al. 1999)
- Evaluates elevation differential between kernel cell and surrounding neighbors
- Reference sites tend to have a higher surface roughness over restoration sites (Diefenderfer et al. 2008).
- The topographic roughness index can be used as a metric for restoration progress and habitat opportunity; e.g., at Sitka spruce swamp sites characterized by hummocky microtopgraphy.



ATIIM Raster Outputs

- Cumulative Frequency of Inundation
  - Cell by cell cumulative frequency over time series