Watershed Restoration: Optimizing Site Selection

(Nehalem Prototype)

Prepared for:
NOAA, ODFW & Nehalem Watershed Council)
by:
TerrainWorks (NetMap)/www.terrainworks.com
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The National Oceanographic and Atmospheric Administration (NOAA) along with Oregon Department of Fish and Wildlife (ODFW) and Watershed Councils, commissioned a pilot project in the Nehalem River watershed in northwestern Oregon to evaluate how the watershed analysis system, NetMap, could be used to support restoration planning, focusing on aquatic, riparian and road related issues pertaining to coho salmon. In part, the NetMap pilot project will be used to support the proposed NOAA coho delisting strategy for the Oregon Coast Range.

This powerpoint allows one to take a self guided tour of the analysis results. To see the movie of the full presentation, go to: https://vimeo.com/119868365

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Objectives:

Being Strategic and Effective with Limited Stream and Watershed Restoration Funds

Optimizing Restoration Outcomes

TerrainWorks (www.terrainworks.com)

The objective of using NetMap is to increase effectiveness in restoration given limited stream and watershed restoration funds, and to optimize restoration outcomes.

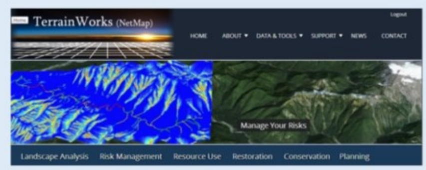
NetMap?

ArcMap

-standard GIS capabilities
-NHD stream layer
-or ArcHydro
-other data layers

ArcMap with NetMap

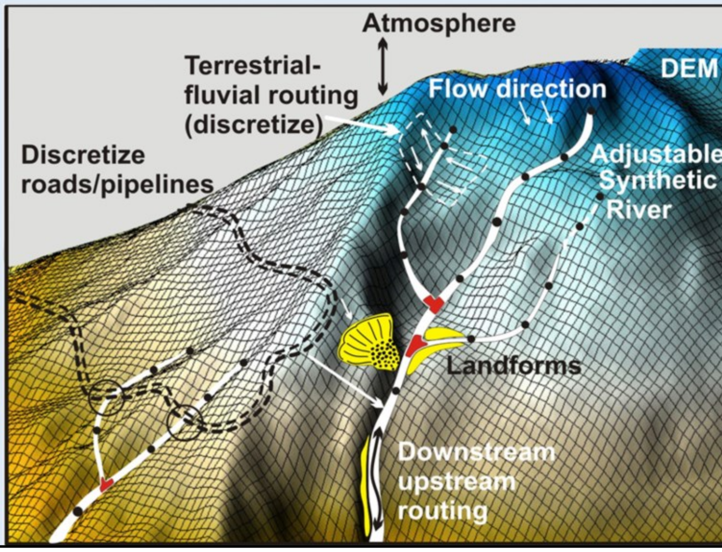
-virtual watershed (synthetic stream layer, landforms, everything connected)
-fish habitat mapping
-floodplains/terraces/fans (riparian areas
-instream wood recruitment
-landslides
-debris flows
-sediment delivery
-gravel supply
-thermal load/shade
-road analyses
road density (basin, reach scale)
road drainage diversion
road surface erosion/sed delivery
road stability
roads in floodplains
habitat length & quality above all crossings
-other resource management &
conservation capabilities



www.terrainworks.com

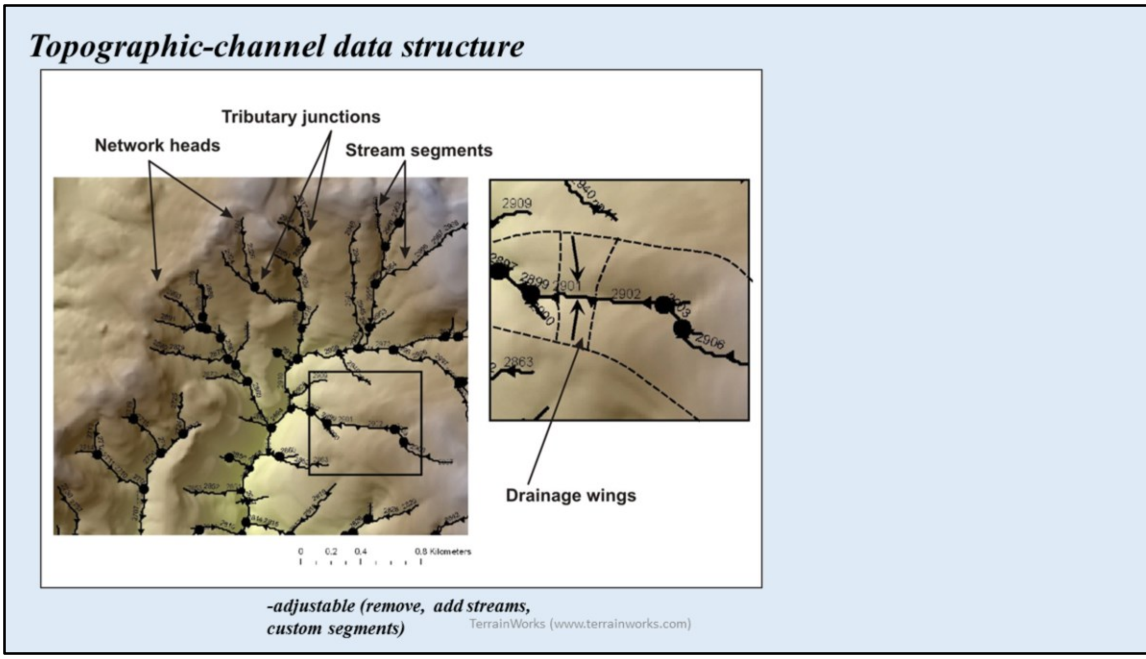
What is the difference between standard ArcMap and the NetMap add-in in ArcMap? NetMap provides a high degree of scientific capabilities addressing a wide range of watershed processes that can inform restoration planning as well as resource management and conservation more generally. To learn more about NetMap, see: www.terrainworks.com

A <u>virtual watershed</u> uses the highest resolution DEMs, includes a routed & attributed synthetic stream layer where stream and rivers are connected to terrestrial environments and land uses



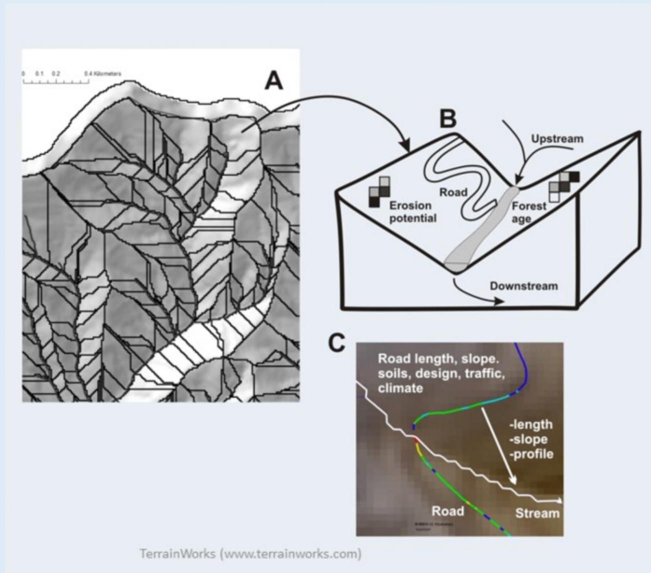
TerrainWorks (www.terrainworks.com)

NetMap uses a “virtual watershed” in the watershed restoration analysis. To learn more about virtual watersheds, go here: http://www.terrainworks.com/digital-hydroscape-virtual-watershed



The data structure of the virtual watershed includes a synthetic river network (derived from DEMs and the NHD) and drainage wings, local contributing areas located on both sides of 100 m channel segments.

Drainage wings (discretize landscapes and land uses)



The drainage wings discretize the watershed terrestrial environment into small areas (approx. 0.1 km^2 in area) and all information on hillsides is then summarized to channels. This supports analysis of aquatic habitat-terrestrial stressor intersections.

Stream layer and landscape attribution

Channel Attributes	Landforms and Process Characterizations
• Gradient	• Floodplains
• Elevation	• Terraces
• Distance to outlet	• Alluvial fans
• Drainage area	• Hillslope-gradient and
• Mean annual flow	convergence (mass wasting)
• Stream order	• Tributary confluences
• Channel width and depth	• Erosion potential
• Bed substrate	• Hillslope–slope profile
• Channel sinuosity	(surface erosion)
• Channel classification	• Valley width and transitions
• Fish habitats	• Debris flows
• Radiation loading	• Earthflows
• Mean annual precipitation	

TerrainWorks (www.terrainworks.com)

The channel network is attributed with information useful for restoration planning. Landform and process characterization is another benchmark attribute of NetMap's virtual watersheds.

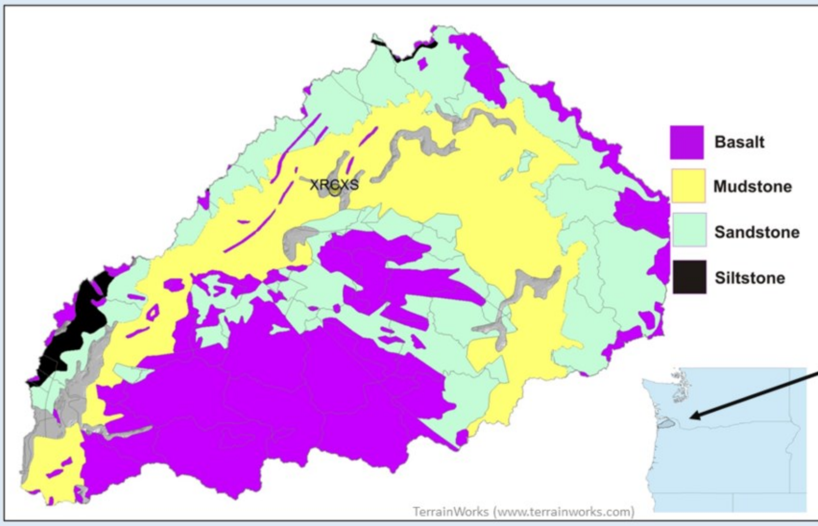
NetMap: A collaborative enterprise since 2007

-National Forests (WA, OR, NCA, AK, ID, MT)
-Forest Service Research: PNW; PSW, RMRS
-USFWS
-NOAA
-BLM
-EPA
-Oregon Dept of Forestry
-OR/WA Fish and Wildlife
-NGOs (TNC, Ecotrust, Wild Salmon Center)
-Watershed Councils
-Universities
-Private
-International

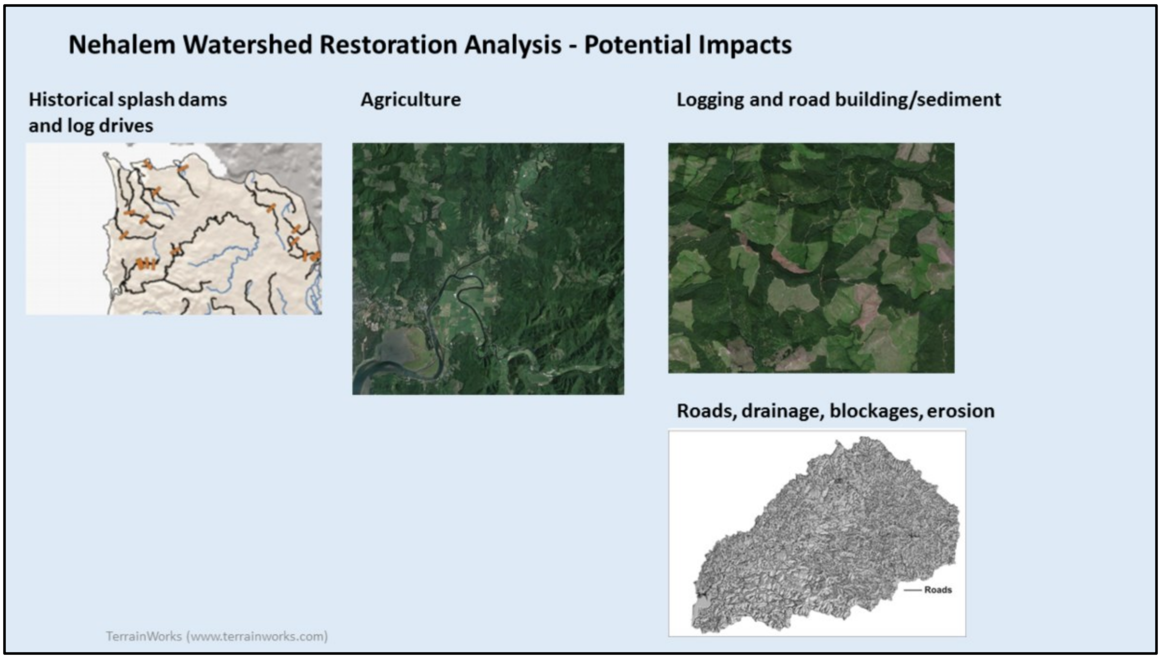
TerrainWorks (www.terrainworks.com)

NetMap is a collaborative enterprise since 2007 and is designed to provide decision support in resource management, restoration and conservation across numerous agencies and NGOs.

Project area and geology



Project area
Nehalem Watershed
Northwest Coastal
Oregon 2,200 km^2)



Historical land uses have impacted fish habitats in the Nehalem basin.

In the Nehalem River watershed, the restoration target species is coho salmon (*Oncorhynchus kisutch)*

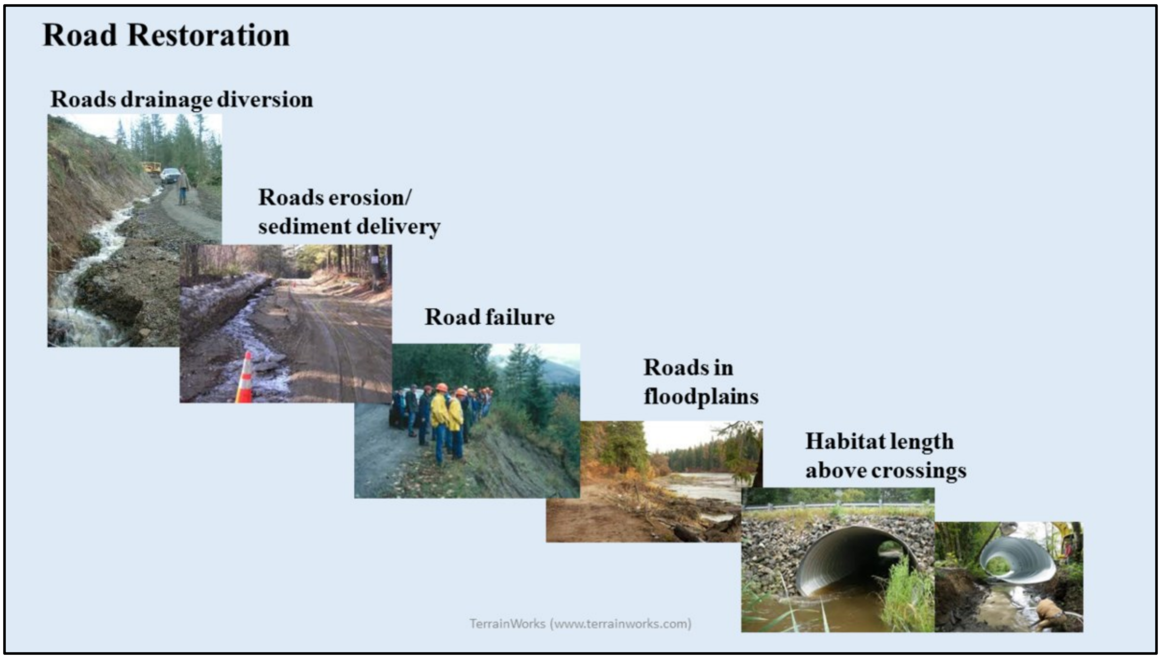
Project elements:

1) Using NetMap create prototype Watershed Restoration Analysis methodology
2) Create prototype work flow
3) Create new NetMap LiDAR based watershed datasets
4) Demonstrate the approach in the Nehalem watershed
5) Potential to extend to other areas (ESUs)

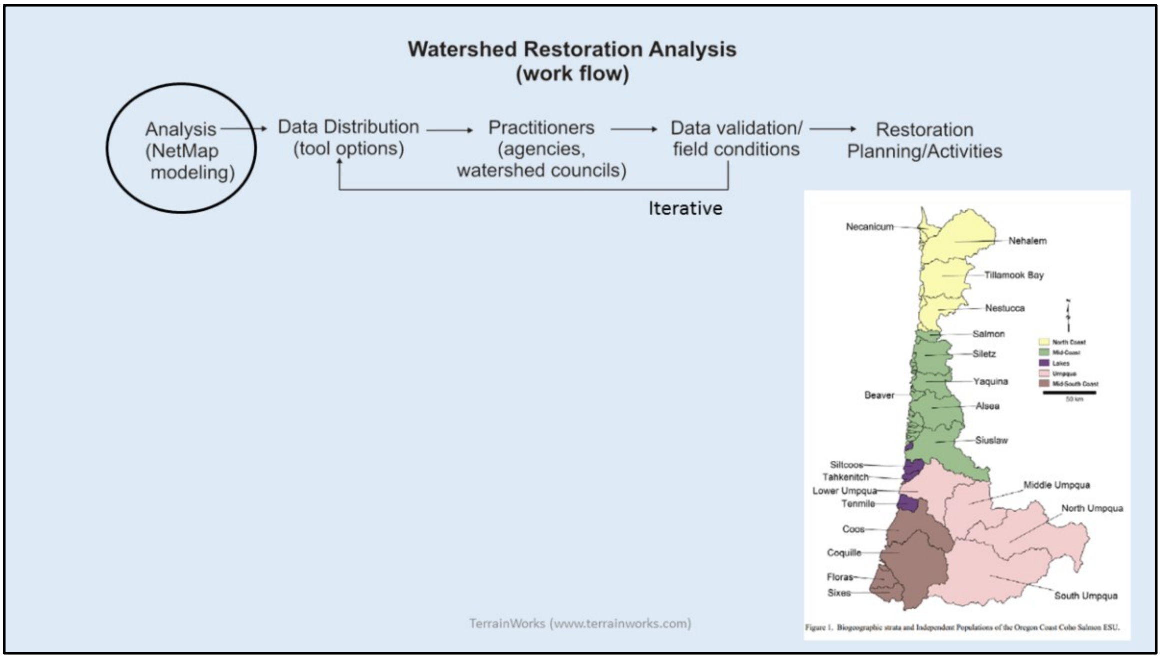
TerrainWorks (www.terrainworks.com)

Project elements.

Restoration targets in the Nehalem Watershed

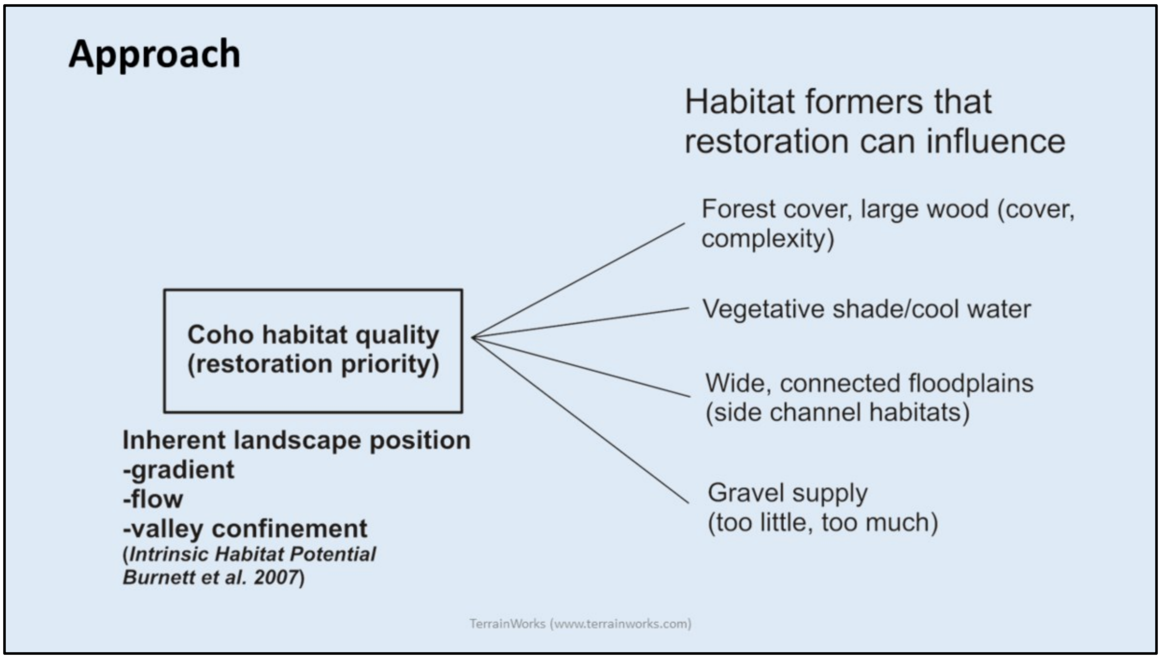


Road restoration can encompass numerous aspects, all of which are included in NetMap's analysis of the Nehalem watershed.

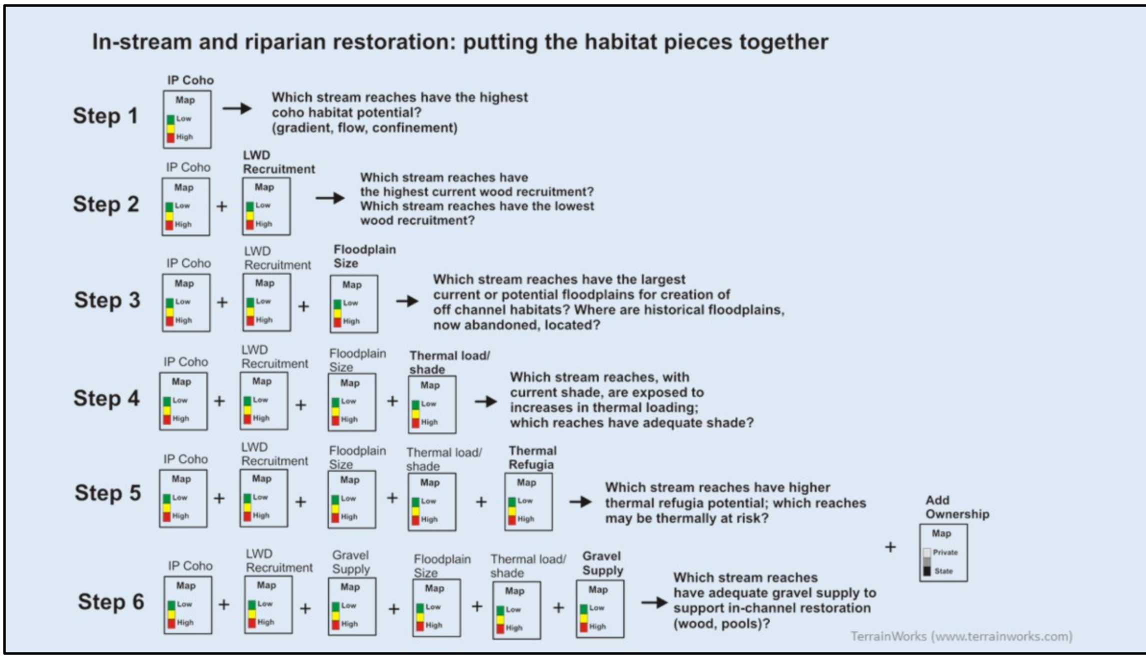


The analysis, data distribution, data validation and restoration planning workflow. During this presentation, we will concentrate on the first step in the workflow.

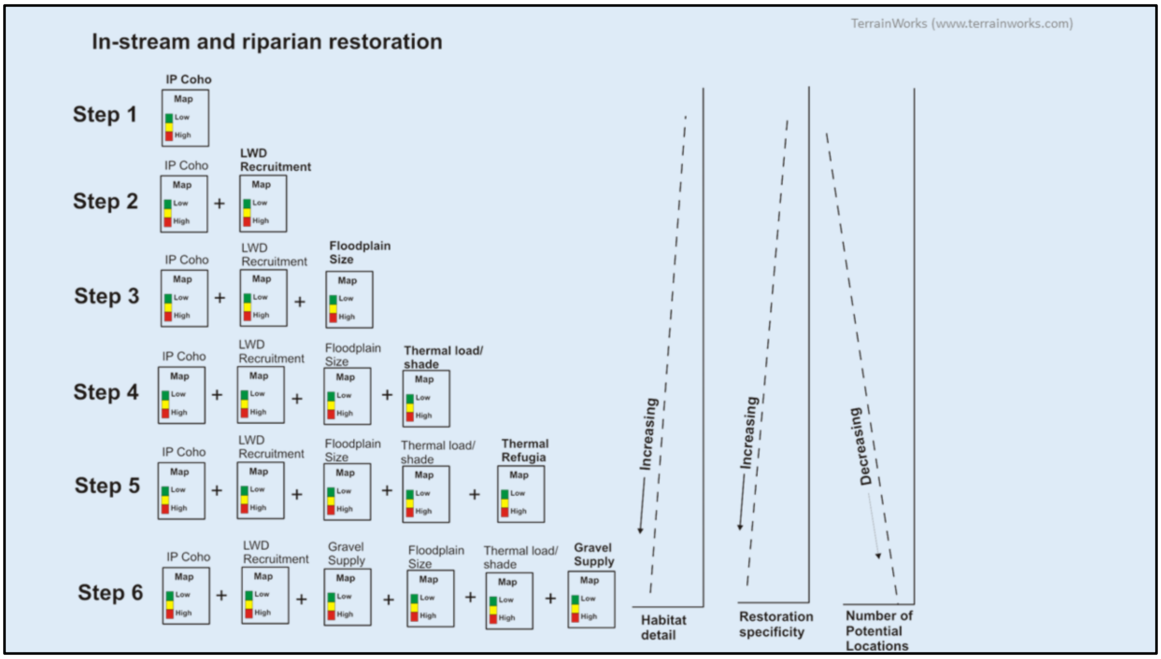
Map at right shows the coho watersheds in the Oregon Coast Range landscape.



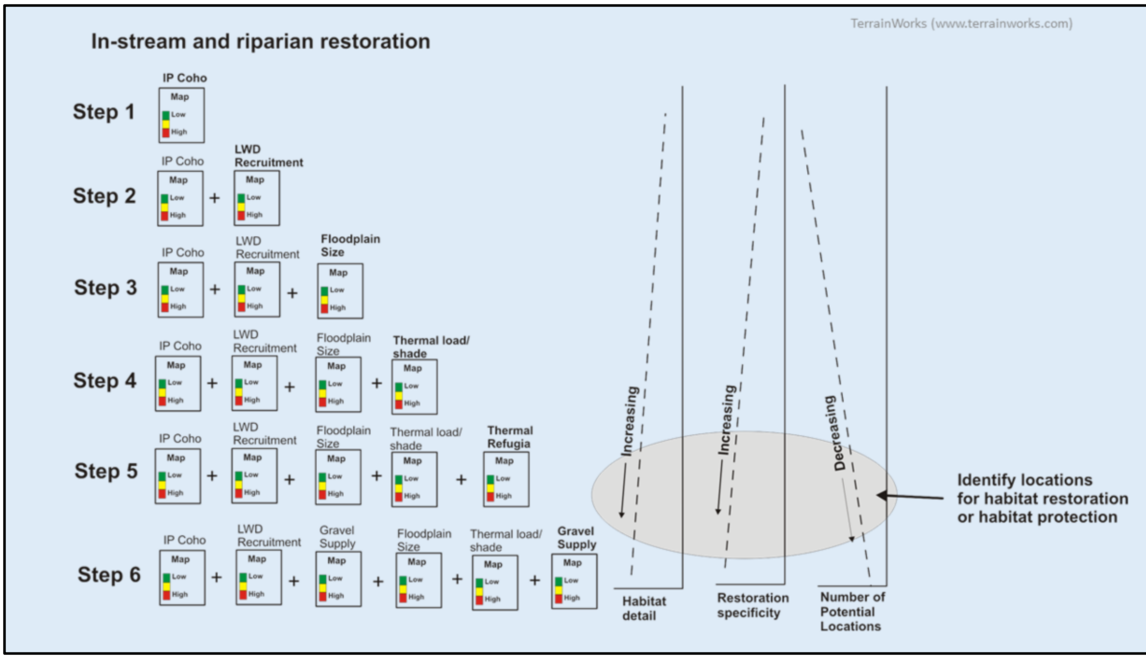
The overall approach to optimizing restoration is to evaluate, via remote sensing data, the inherent landscape position required for habitat development of coho ("intrinsic habitat potential, or IP for short) and the habitat forming processes such as riparian vegetation (shade), riparian tree size (large wood recruitment), floodplain extent and connectivity (side channels) and gravel supply (not too little, not too much).



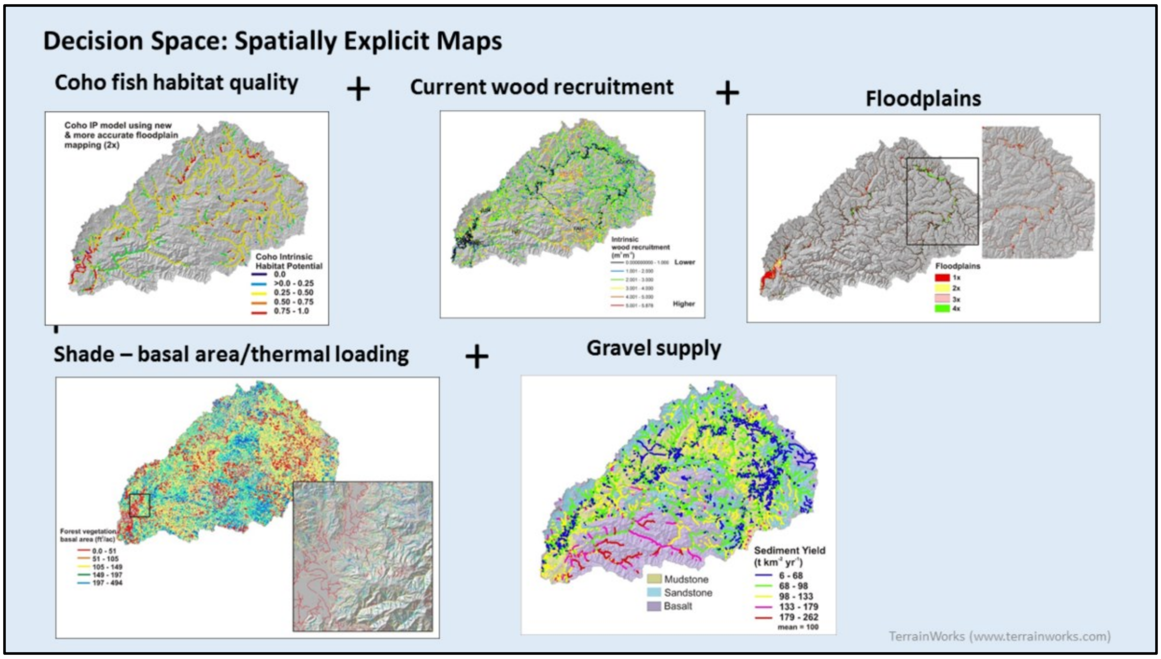
The approach to the NetMap Watershed Restoration Analysis is to combine spatial information from five data sources (others could be added, including for roads, see later). Data sources include: 1) landscape position described by intrinsic habitat potential models, 2) in-stream wood recruitment, 3) gravel supply, 4) floodplain size, and 5) shade, conditioned by stream thermal sensitivity. Other factors could be added including tributary confluences (e.g., thermal refugia), erosion potential and land ownership.



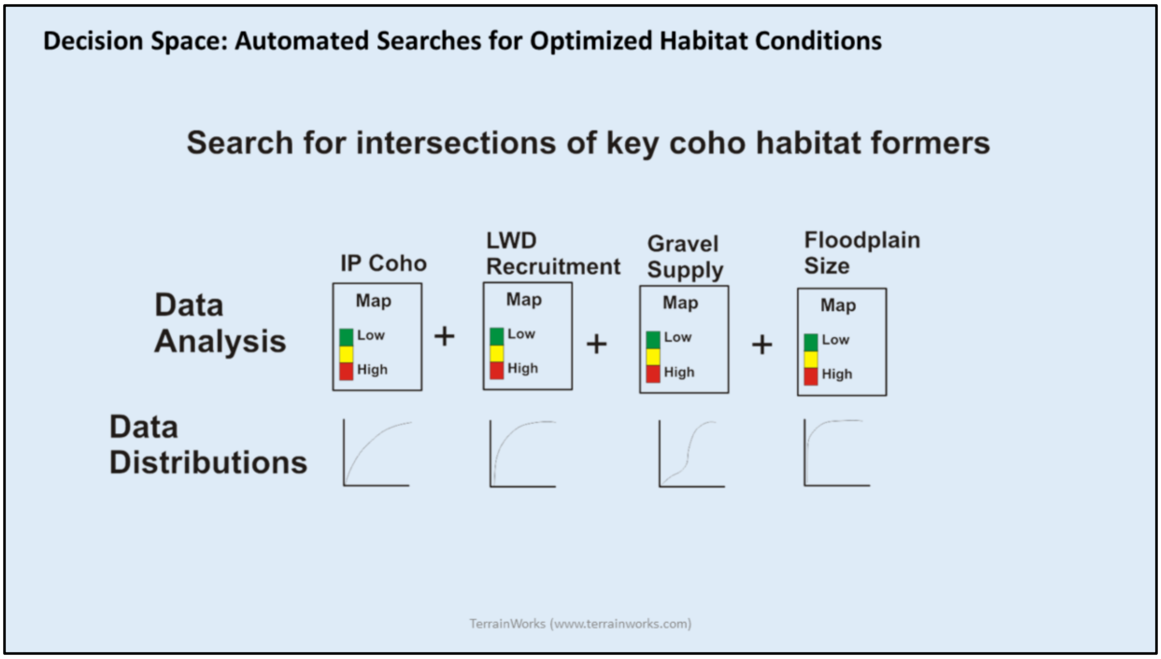
Combining all of these habitat forming factors, with the objective of optimizing restoration, leads to several outcomes including 1: habitat detail increases, 2) restoration site specificity increases, and 3) the potential number of restoration sites decreases. In other words, the number of locations in a watersheds where all the factors are optimized is reduced.



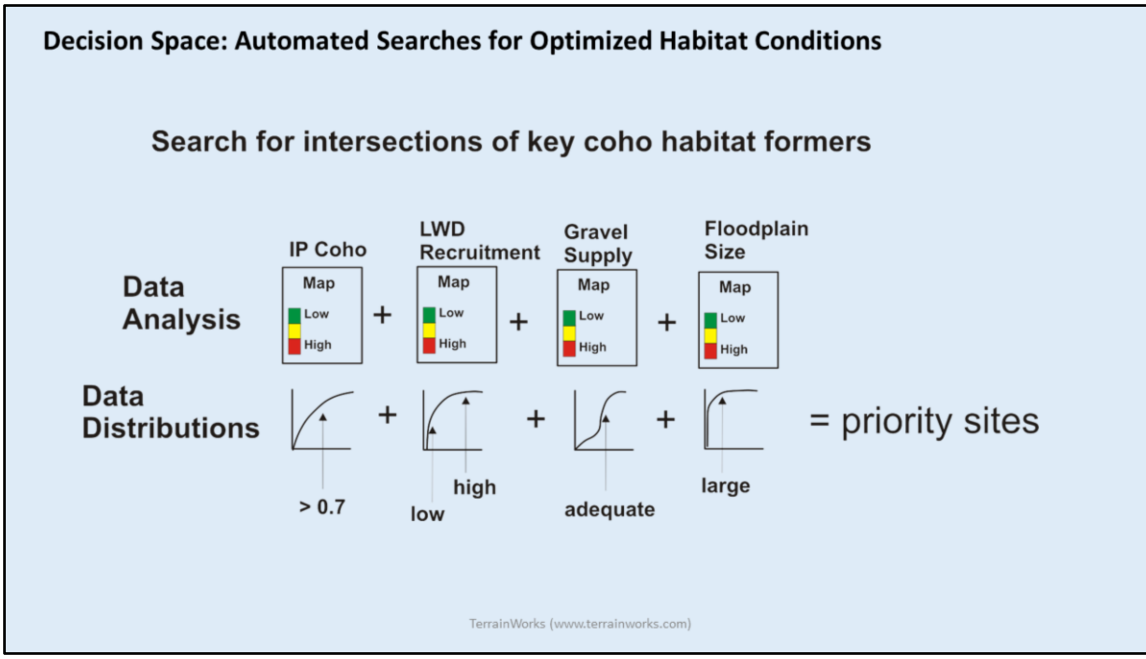
TerrainWorks (www.terrainworks.com)
In-stream and riparian restoration
Step 1
IP Coho
Step 2
IP Coho
LWD Recruitment
Step 3
IP Coho
LWD Recruitment
Floodplain Size
Step 4
IP Coho
LWD Recruitment
Floodplain Size
Thermal load/ shade
Step 5
IP Coho
LWD Recruitment
Floodplain Size
Thermal load/ shade
Thermal Refugia
Step 6
IP Coho
LWD Recruitment
Gravel Supply
Floodplain Size
Thermal load/ shade
Gravel Supply
Map
Low
High
Increasing
Increasing
Decreasing
Habitat detail
Restoration specificity
Number of Potential Locations
Identify locations for habitat restoration or habitat protection



Decision Support Space 1: Spatially explicit maps of key watershed landforms and processes. In combination, including with other attributes, they can inform restoration planning. For example, where is the best potential coho habitat located and where does it overlap other important habitat forming processes such as wood recruitment, shade and gravel supply.



Decision Support Space 2: Using data frequency distributions to identify attribute thresholds; see next slide.



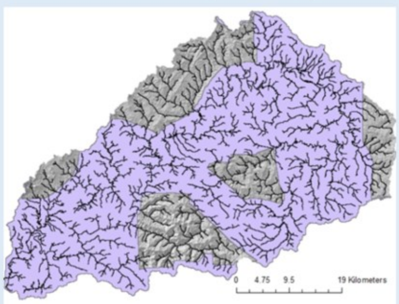
Decision Support Space 2: Analysts select thresholds such as > 0.7 coho IP to identify locations where those habitat patches overlay with high to low wood recruitment and floodplain size; see examples later in the presentation.

Building the Virtual Watershed: Available Data

2.5 m LiDAR and 10 m digital elevation models (DEMs)

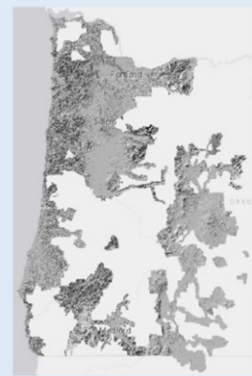
Tasks:

1) LiDAR hydro-conditioned DEM
2) Channel head calibration – where do channels begin?
3) Synthetic stream derivation (21,400 individual segments, average 100 m length)
4) Network line check: remove flow diversions by roads
5) Attribution
6) Routed (downstream/upstream)

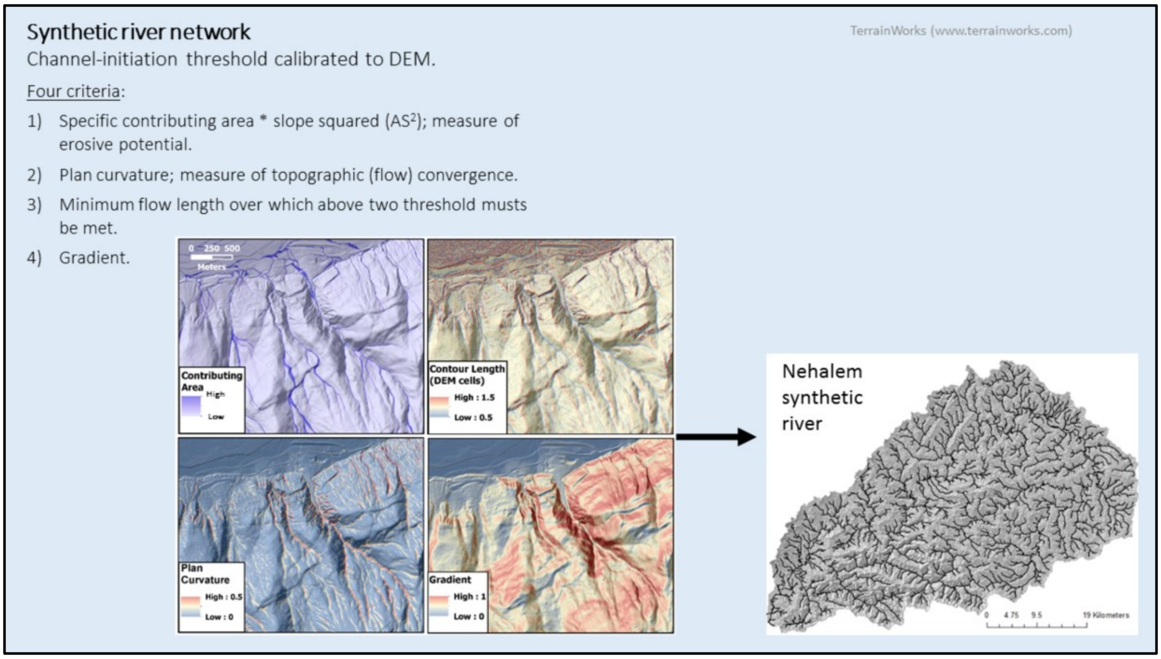


LiDAR coverage in purple

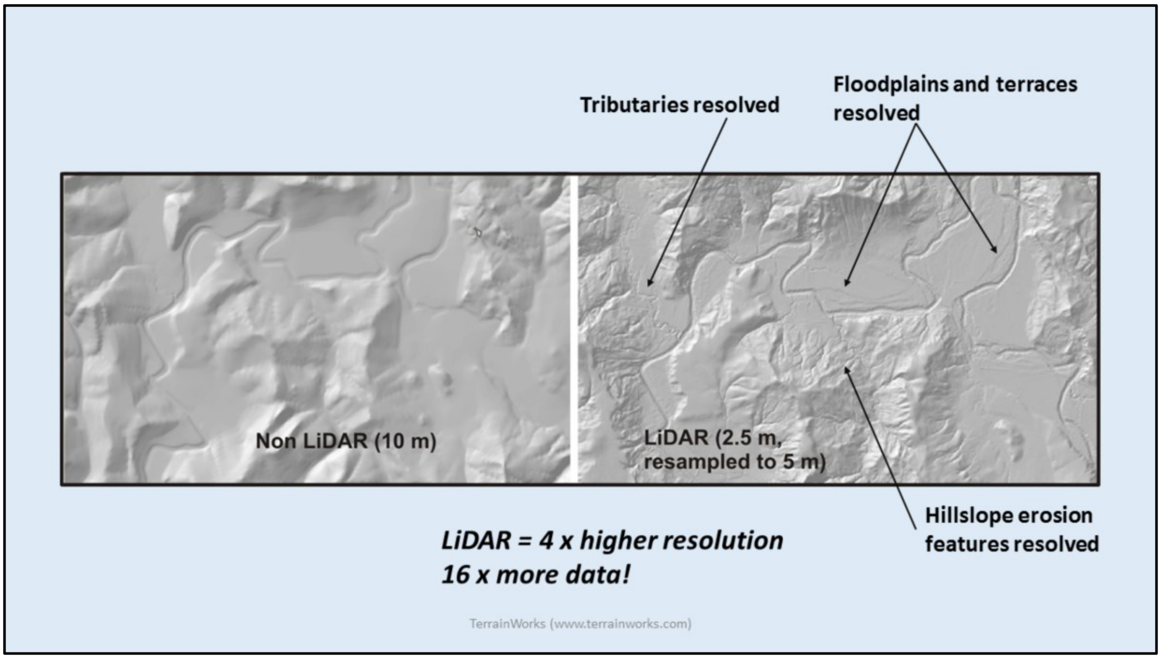
TerrainWorks (www.terrainworks.com)



Available data to build a virtual watershed include 10 m and 2.5 m LiDAR digital elevation models (DEM). Tasks involved are listed.

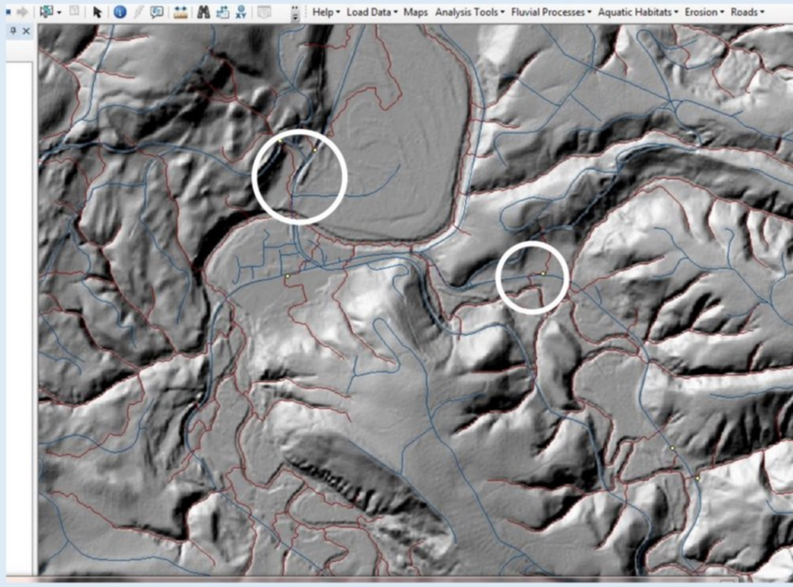


NetMap's synthetic river network is based on a comprehensive analysis of channel forming processes.



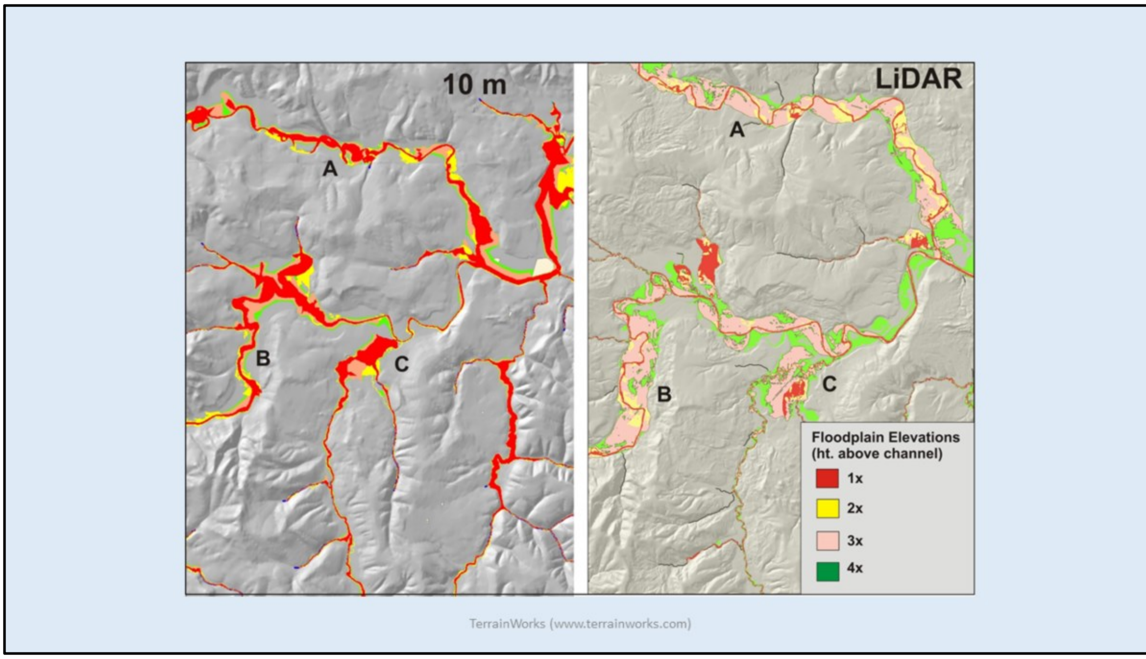
LiDAR or mixed LiDAR-10 m DEMs can resolve numerous details in our virtual watershed.

Roads in LiDAR DEMs are often seen as topographic features and cause drainage diversions that need to be corrected



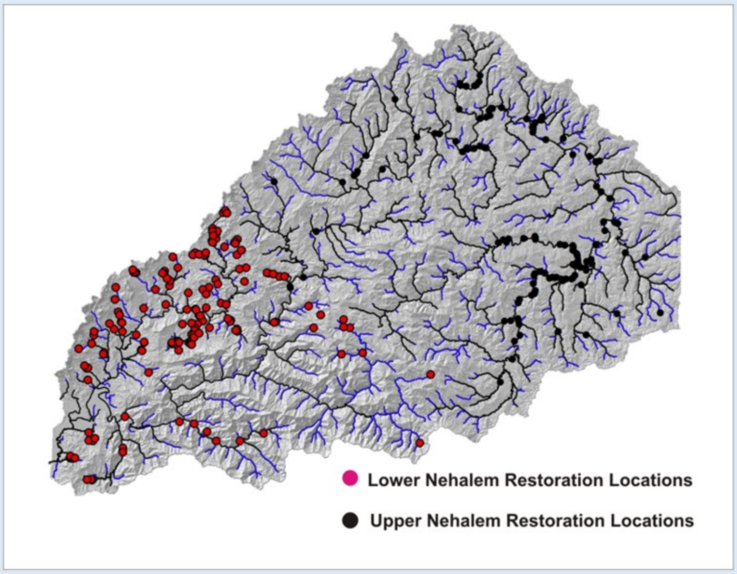
TerrainWorks (www.terrainworks.com)

Roads are seen as topographic features in LiDAR and the resulting drainage diversions need to be addressed when building the synthetic river network



NetMap’s floodplain mapping tool works with either 10 m or with LiDAR, although the LiDAR based floodplain maps provide considerably more detail (right panel).

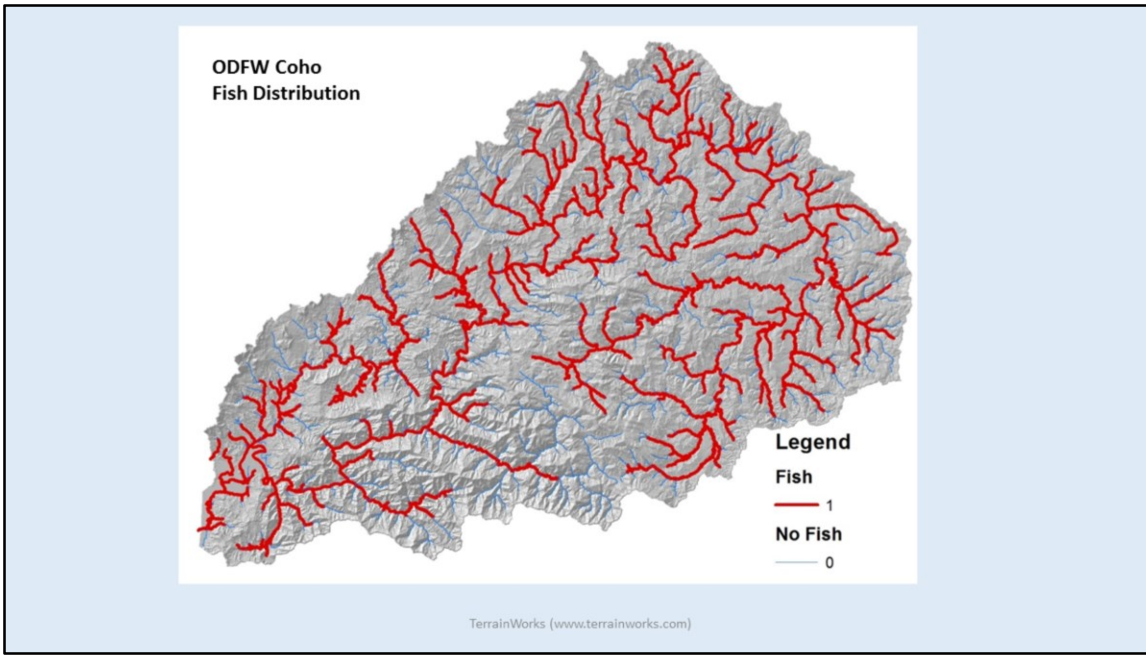
This section of the powerpoint presentation will cover the NetMap analysis pertaining to stream and riparian restoration; analysis of road restoration opportunities will come later.



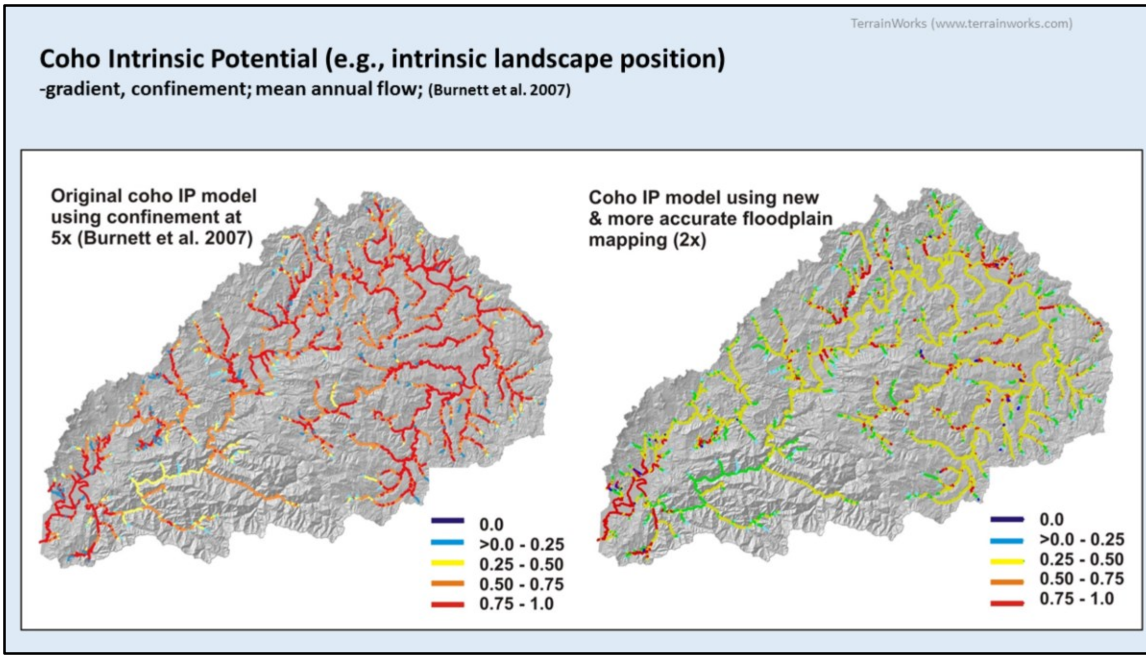
How do the sites compare to predicted hotspots for coho habitat?

TerrainWorks (www.terrainworks.com)

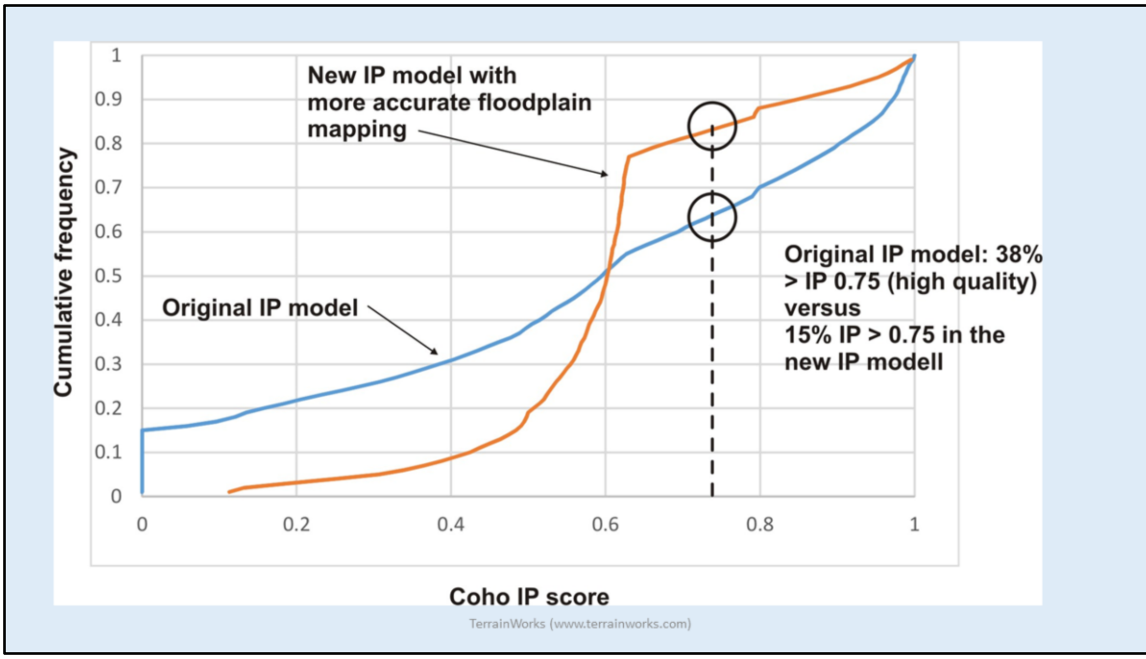
As part of the Nehalem analysis, we will compare the locations of existing restoration projects, primarily those related to in-stream and riparian areas, to predicted and mapped environmental characteristics related to fish habitat quality, floodplains, large wood recruitment and shade. In other words, are existing restoration projects located in areas that would optimize fish habitat restoration? See for yourself as we move on with the presentation.



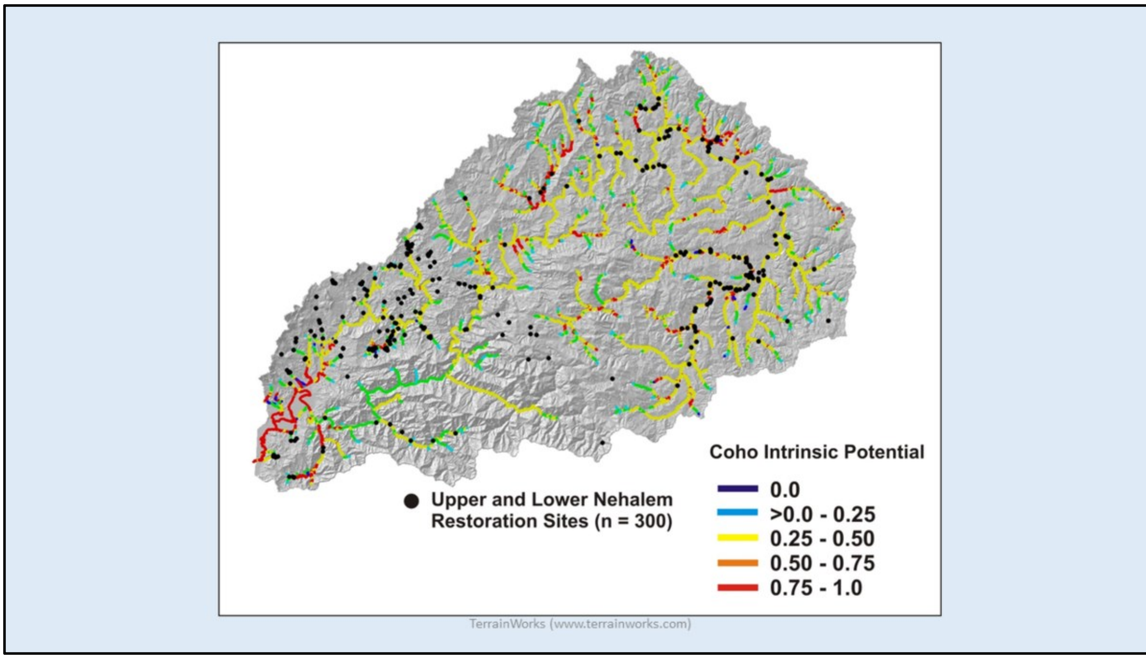
First off, to map coho fish habitat quality we will use the distribution of coho salmon in the Nehalem watershed available from the Oregon Department of Fish and Wildlife, shown by the red network.



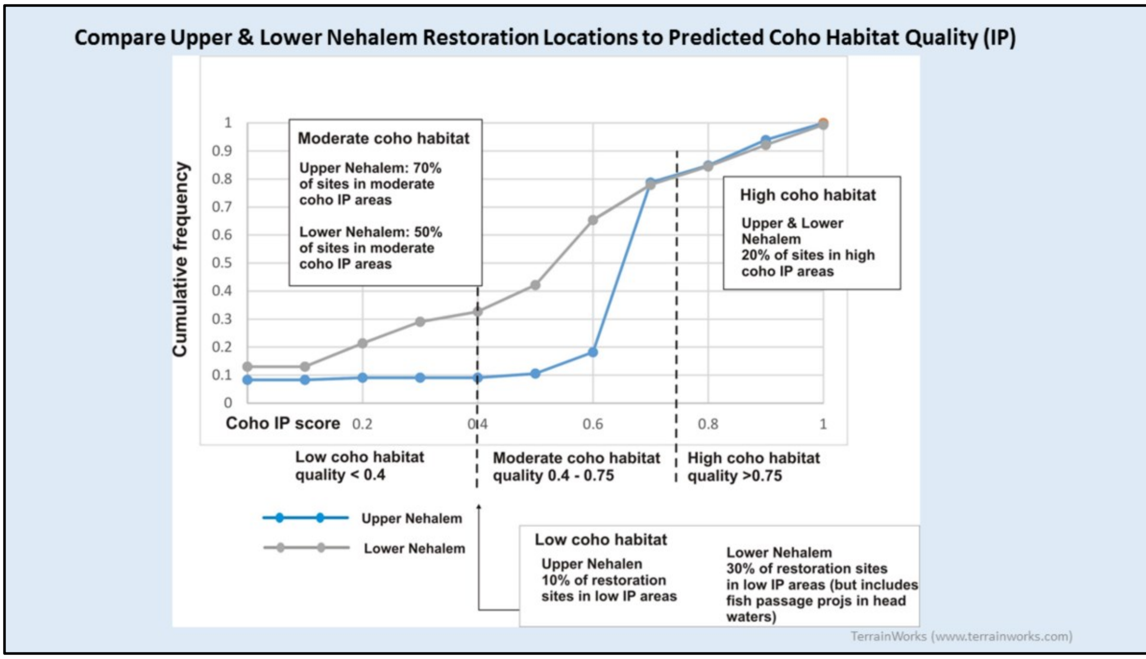
The first step is to map fish habitat according to intrinsic landscape position, known as "intrinsic habitat potential" or "IP". The original coho IP model was developed more than a decade ago, including in the Oregon Coast Range, and was based on lower resolution DEMs and a limited ability to accurately map floodplains (left panel above). We now have the ability to more accurately map floodplain width and hence channel confinement, and this in combination with higher resolution DEMs, including LiDAR, allow for a much more accurate depiction of intrinsic habitat mapping (right panel above). Learn more about this issue here: http://www.terrainworks.com/intrinsic-potential-ip-fish-habitat-modeling-read. See next slide for additional information.



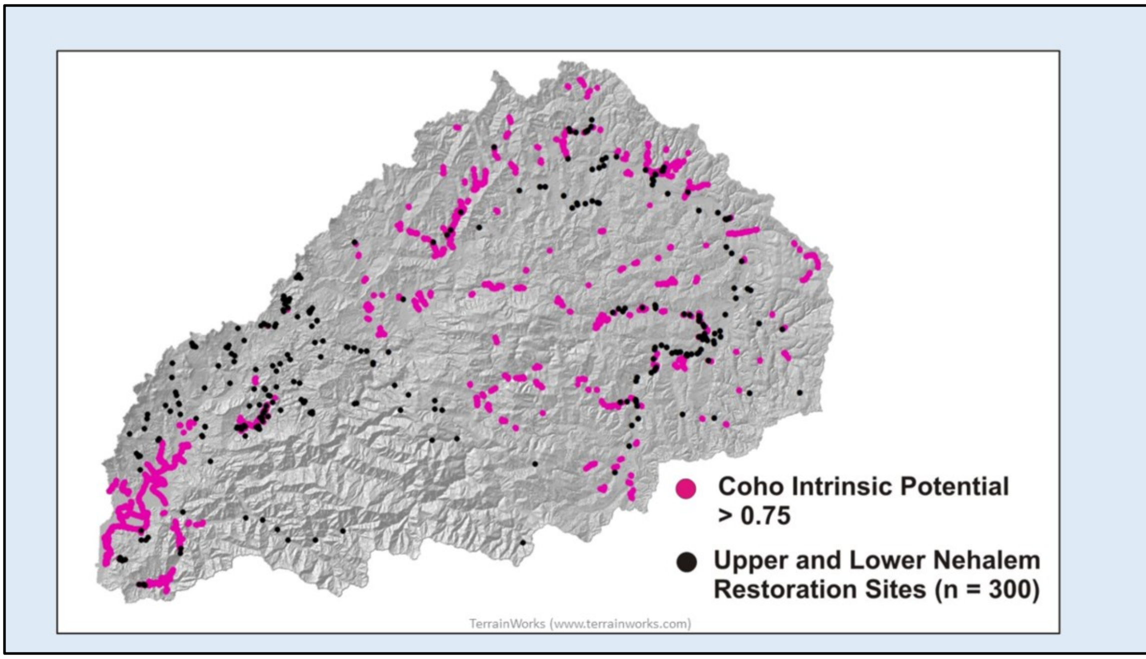
These two cumulative frequency plots show the difference between the original (decade old) IP model scores for the Nehalem watershed compared to the newer (2015) IP scores using advanced floodplain mapping capabilities and the mixed 10 m – LiDAR DEMs. One of the largest differences is the reduction in the highest and lowest IP scores and a large increase in the moderate range of IP. Hence, very good coho habitat quality would be constrained to fewer areas.



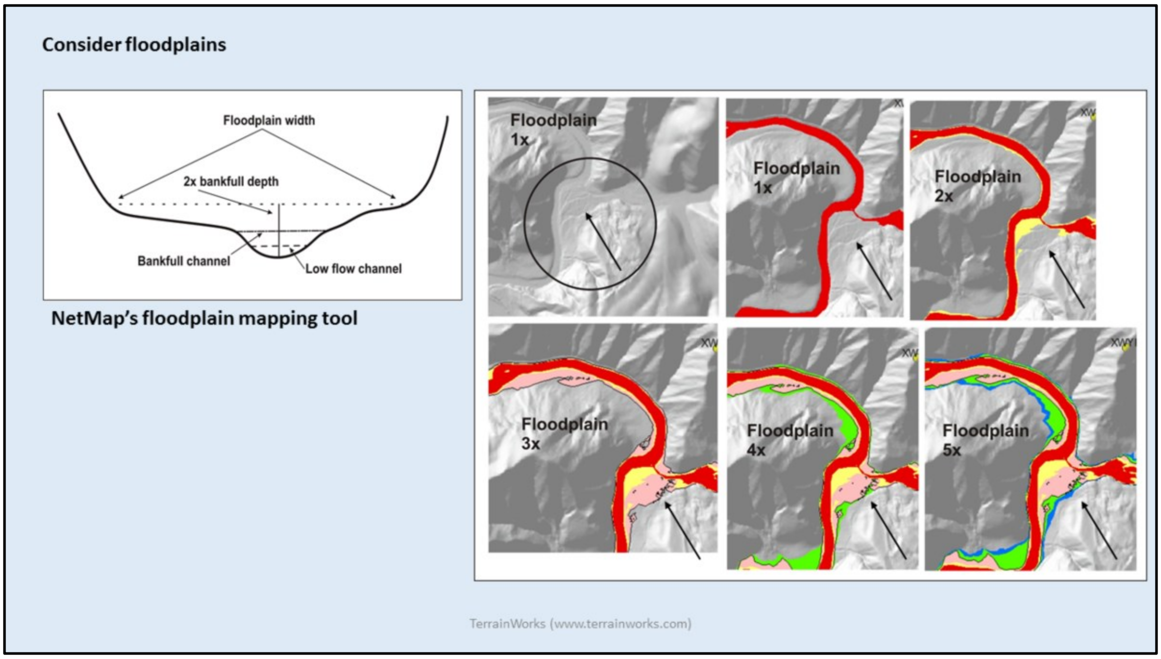
This figure shows the locations of the upper and lower Nehalem restoration sites compared to the predicted coho intrinsic habitat potential. The next slide will show, quantitatively, how the restoration sites compare to the mapped IP scores.



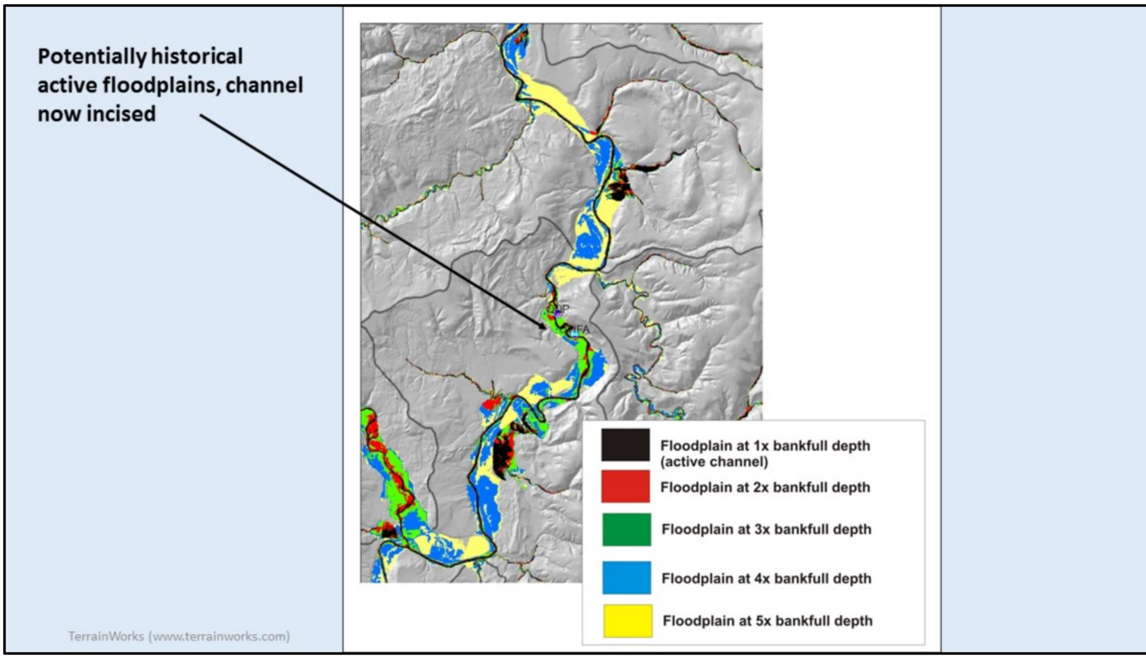
The cumulative frequency plots above show the distribution of existing restoration sites in the lower and upper Nehalem watershed (e.g., associated with the lower and upper Nehalem Restoration Councils). This analysis shows that only about 20% of the restoration locations are located in predicted high coho IP areas. Between 10% and 30% of sites are located in areas of low IP. The majority of sites (50-70%) occurs within the moderate IP areas. This plot suggests that restoration sites may not be targeting the areas with the highest intrinsic site conditions for coho habitats. It may also indicate that restoration sites are targeting areas that currently have a lower IP score but that historically may have had a higher score, due to, for example, floodplain diking and channel downcutting. In either case, the use of modern IP maps could be used to help site future restoration locations. The removal of fish migration (barrier removal) projects in the lower Nehalem does not significantly change the outcome in the plots.



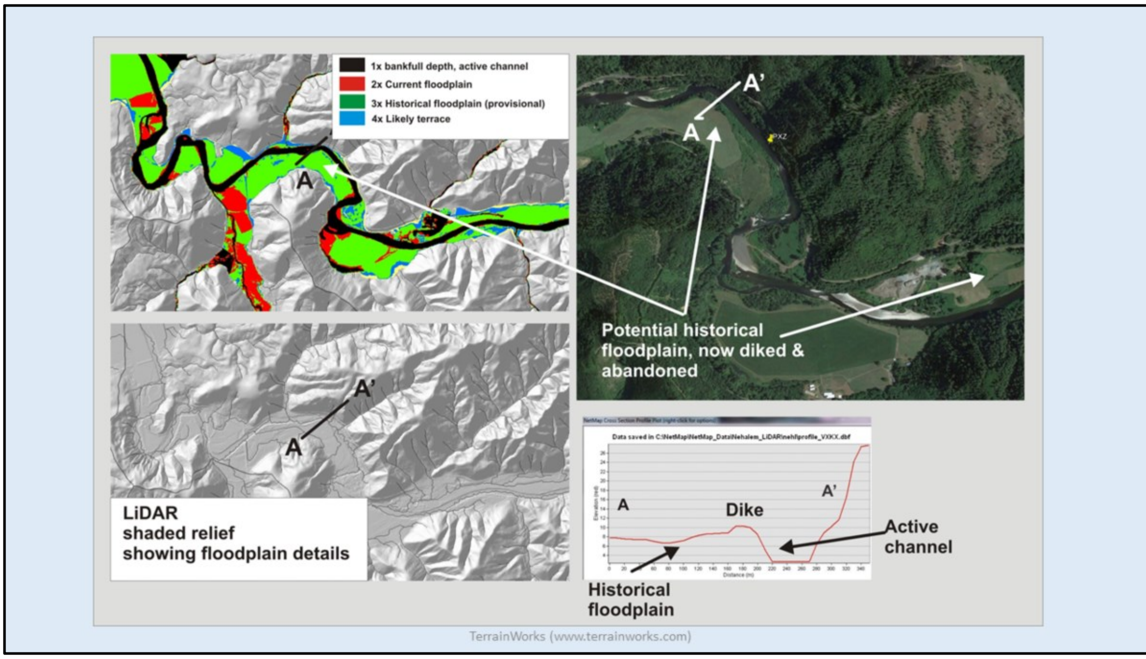
Here is a graphic that illustrates the locations of upper and lower Nehalem restoration locations compared to the highest coho IP scores. In some areas they overlap while in many other areas they do not. Note how coho IP high quality habitats are concentrated in several areas, as well as being more distributed in other areas. There are concentrated hotspots for coho habitats such as the lower floodplains area, currently under agriculture.



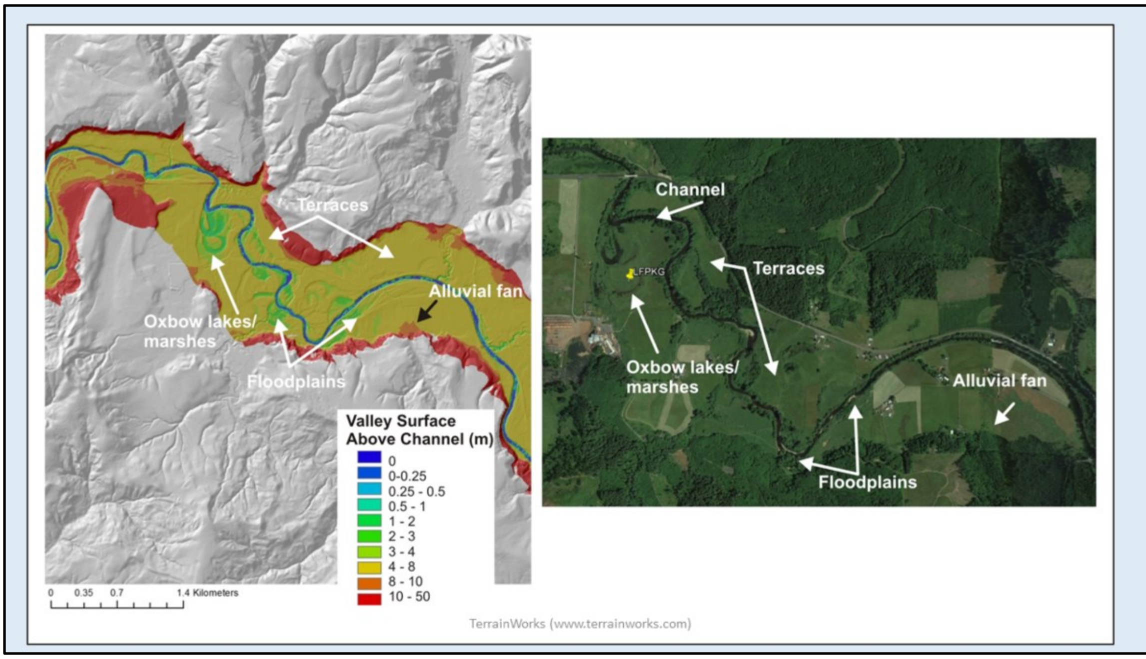
Floodplains are an important constituent of coho habitats and can be targeted for restoration. NetMap's advanced floodplain mapping tool calculates floodplains based on multiples of bankfull depths above the channel. This graphic (right panel) illustrates this using a 2.5 m LiDAR DEM in the Nehalem. Floodplains at 1x bankfull depth defines the active channels; floodplain at 2x defines the current active floodplain; floodplain at 3x defines the higher current floodplain and or the historically active floodplain in channels that have incised; floodplains above 3x are likely terraces that do not get inundated.



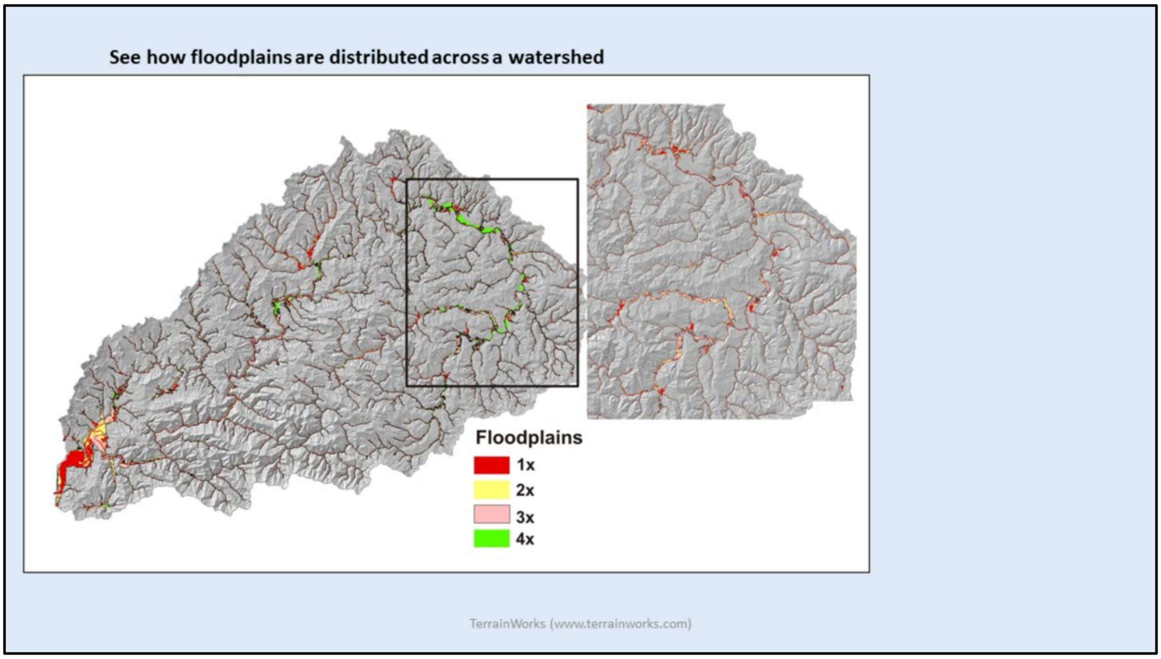
NetMap's floodplain mapping tool can be used to identify current floodplains and abandoned floodplains, those that were once active but currently are non functioning because of dikes and other land uses.



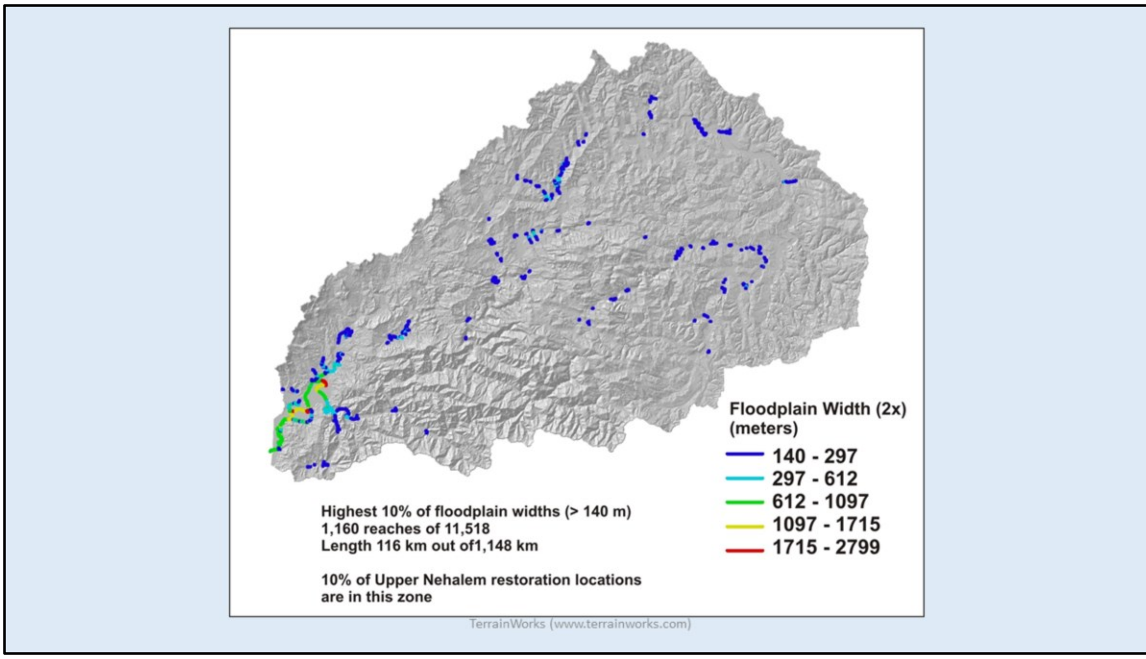
Using LiDAR DEMs, the floodplain mapping tool can be used to detect the effects of dikes in isolating floodplains from their river systems, as illustrated above.



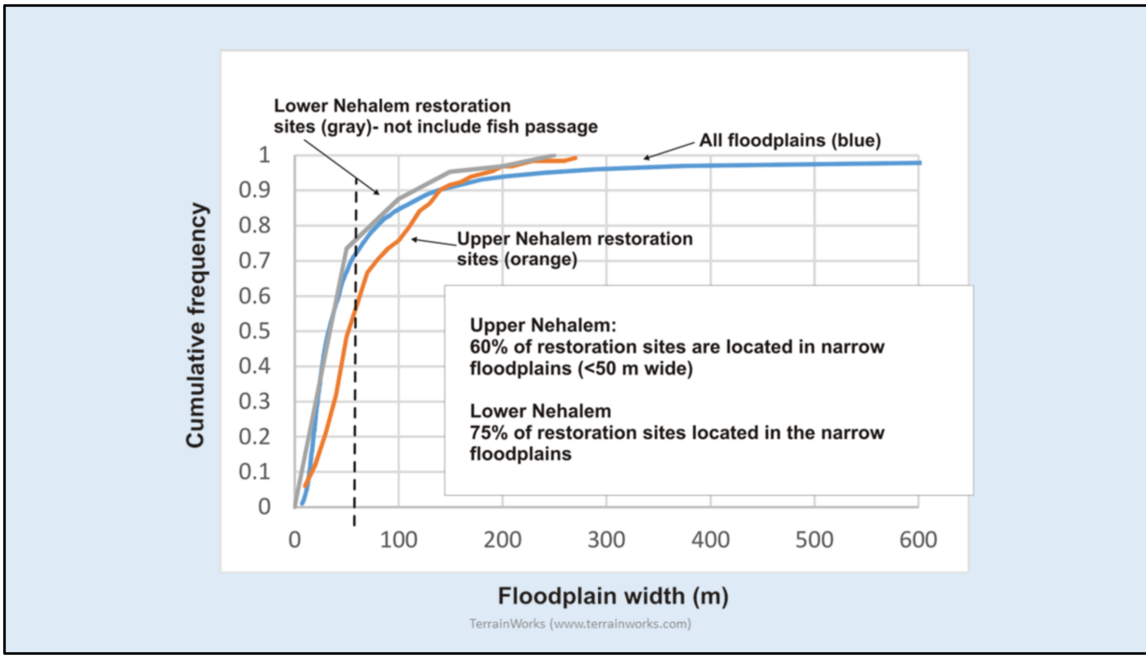
NetMap's valley floor mapping tool can identify landforms including channels, floodplains, oxbow lakes, marshes, terraces and alluvial fans. This information could be used to help prioritize restoration projects, particularly those designed to reconnect channels with their floodplains.



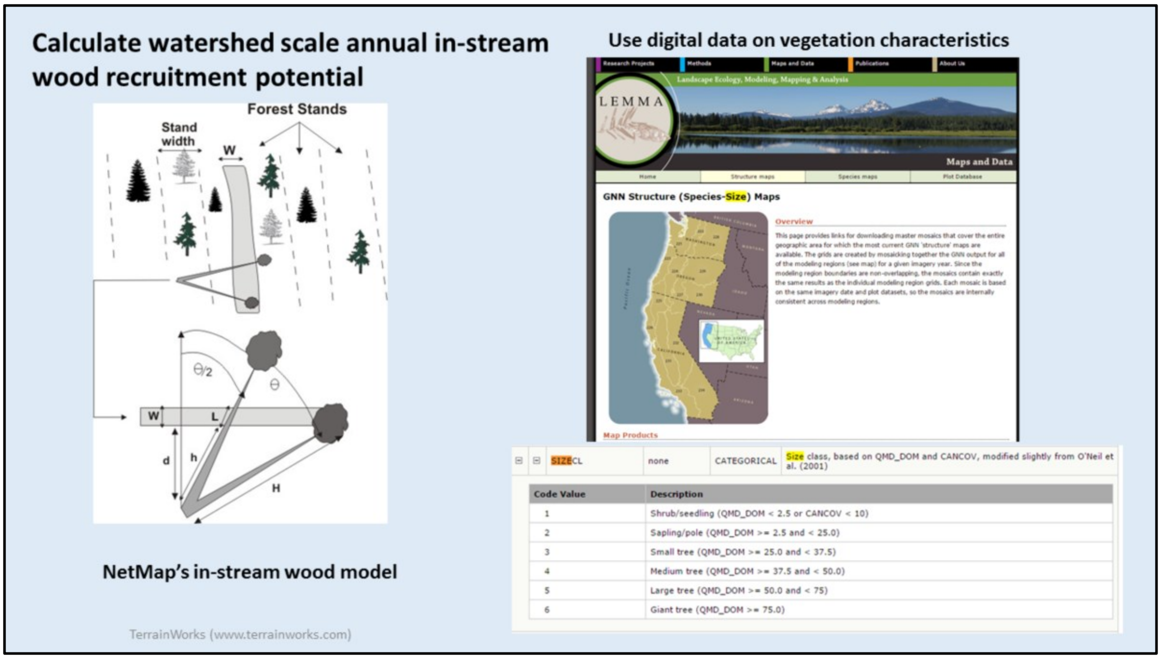
This map shows how floodplains and terraces are distributed across the Nehalem watershed. There are pockets of larger floodplains shown in red and yellow on the map.



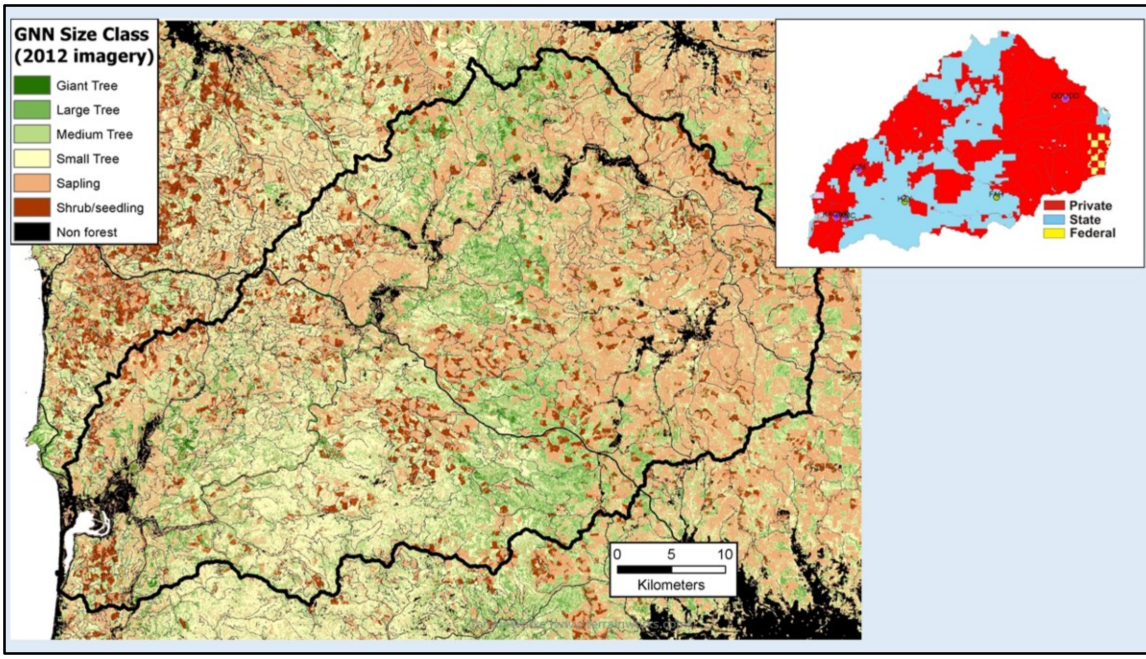
Here we see the locations of the largest (widest) 10% of floodplains in the Nehalem watershed. For example, only 10% of the upper Nehalem existing restoration locations are located in the widest floodplains. See next slide for a more detailed comparison.



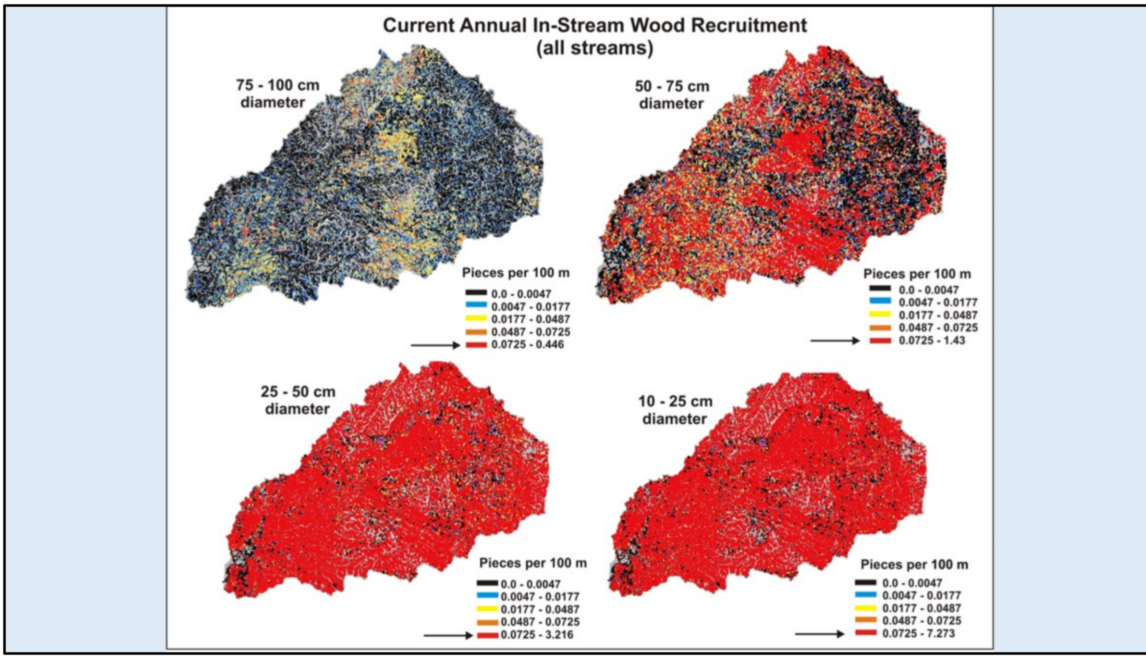
The figure shows the cumulative frequency plots of the lower and upper Nehalem that reveal that current restoration sites are not targeting the areas of the widest floodplains. This is probably due to the fact that the largest floodplains in the Nehalem are under agriculture land use. However, this finding might also point to an opportunity to extend restoration activities to wide floodplains, if land use issues can be overcome.



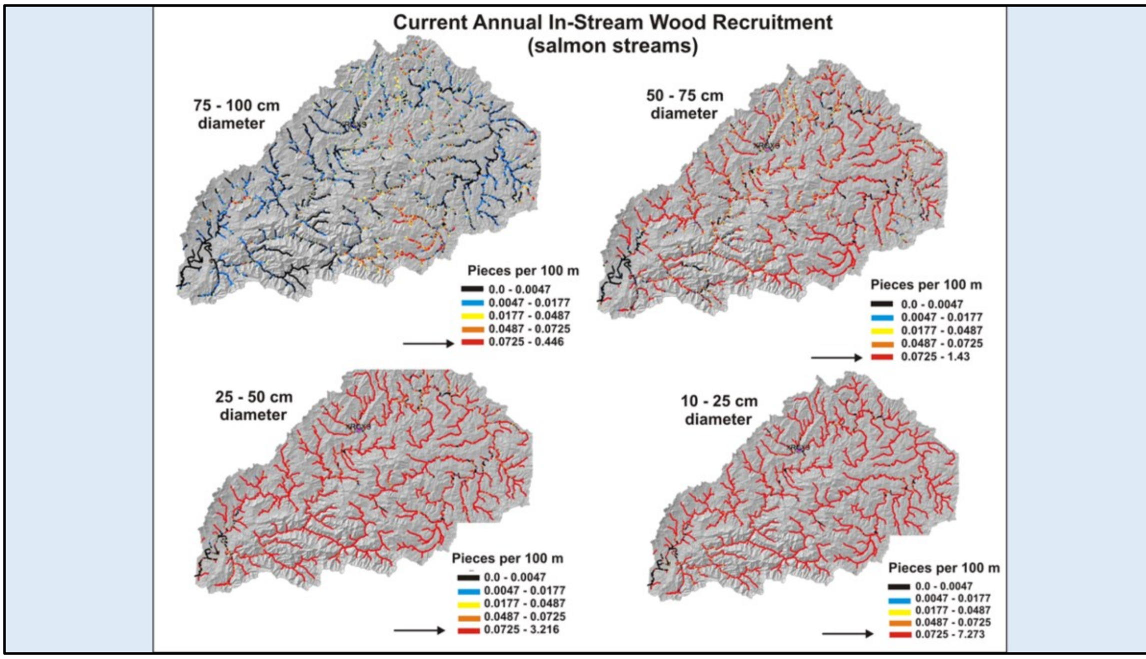
Another important fish habitat component is in-stream wood recruitment



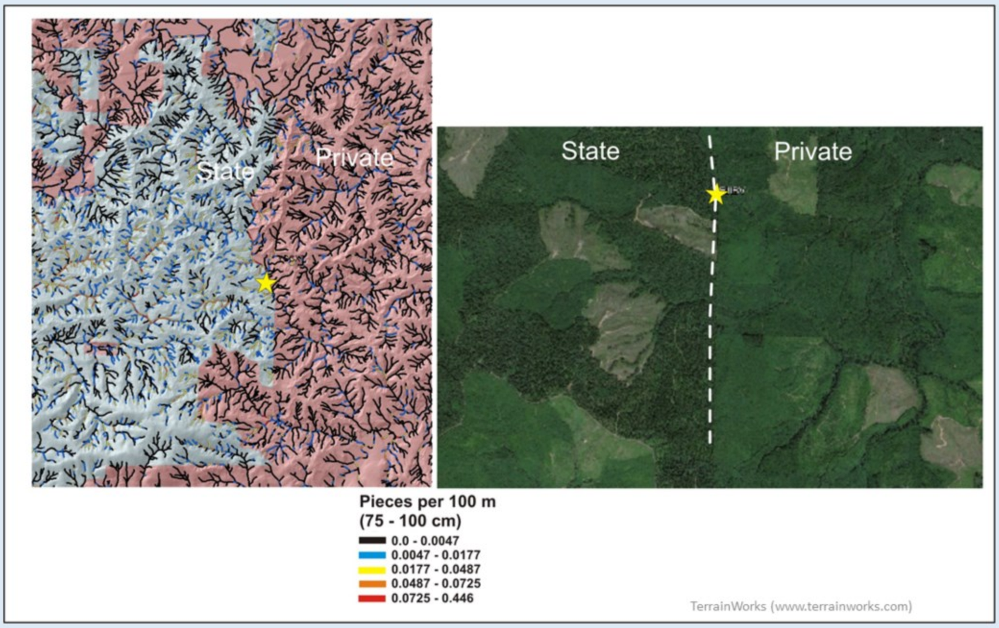
Remote sensing data from LEMMA is used in NetMap's watershed scale wood recruitment tool. Here we can see the distribution of vegetation/tree sizes across the Nehalem watershed. The ownership map in the top right corner that shows the distribution of private and public (state) lands corresponds in large part to the distribution of tree sizes. The dominance of small trees and saplings is concentrated in the private lands. However, many streams, particularly fish bearing, do have vegetation buffers that include larger trees (not easily seen in the watershed scale map).



NetMap's watershed scale wood recruitment tool reveals patterns of potential in-stream wood loading from headwaters to salmon streams. All legend classes are the same across all four diameter classes, with the exception of the highest values (denoted by arrows). Darker colors (black/blue) indicate low wood loading for size classes and the warmer colors (orange/red) indicate higher wood loading (pieces/100 m). Wood recruitment of larger size classes (75-100 cm) is low in many areas of the watershed but there are areas of higher recruitment in some local areas (e.g., patches of larger trees). Overall, there are much greater amounts of wood recruitment in the moderate to small diameter classes. Such information could be used to help prioritize restoration site selection.

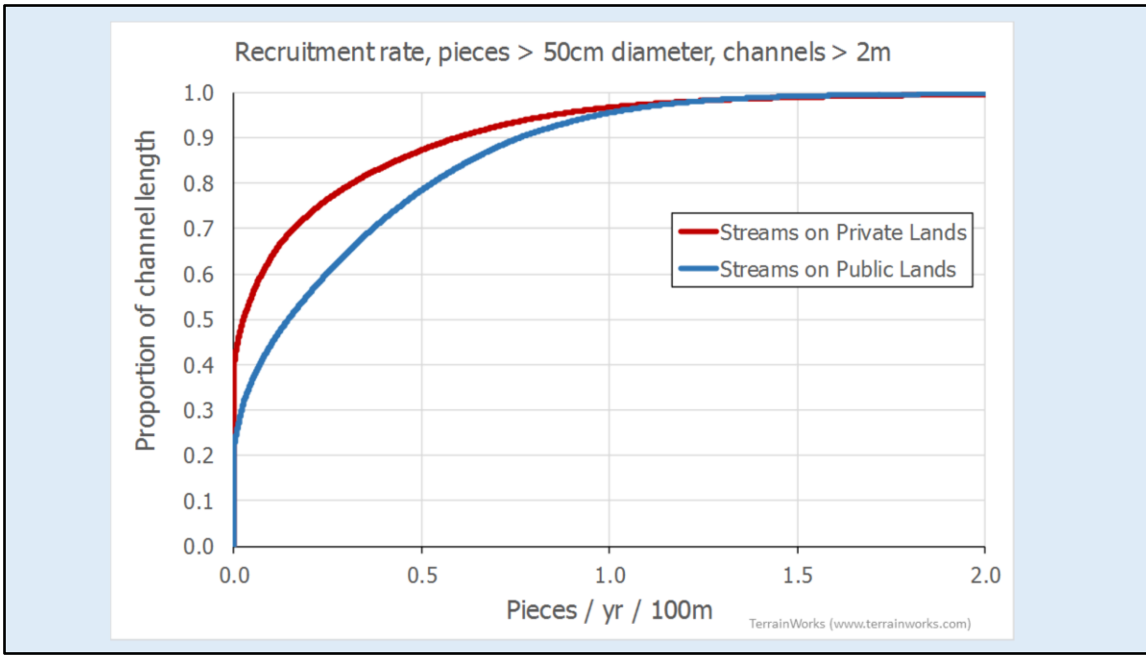


NetMap's watershed scale wood recruitment tool reveals patterns of potential in-stream wood loading for salmon streams. All legend classes are the same across all four diameter classes, with the exception of the highest values. Darker colors (black/blue) indicate low wood loading for size classes and the warmer colors (orange/red) indicate higher wood loading (pieces/100 m). There are patches of higher wood recruitment for the larger diameter classes (upper left). Many fish streams have higher levels of recruitment but of the smaller diameter classes. Areas of high to low recruitment of large to small wood could be matched up with higher intrinsic potential (IP) scores and used to help prioritize restoration site selection.



Zooming in on predicted annual wood recruitment of the largest size classes show a distinct difference in wood loading potential. For the largest piece size class, headwaters in private lands have very low values because very few buffers are required. State lands have some buffers in headwaters, leading to higher predicted wood recruitment in some locations, but some headwaters on state lands also can have low wood loading due to historical and present day timber harvest. Along fish bearing streams overall, private lands have low to moderate

levels of wood loading for the largest piece sizes while state lands wood loading varies from lower to higher values, depending on the history of land use activities, including timber harvest.



The cumulative distributions of recruitment rates are derived from the previous wood recruitment map. Note that only about 4% of the network gets recruitment rates > 1pc/yr/100m (pieces > 50 cm diameter). However the cumulative distributions above provide another perspective of watershed scale wood loading, including the pattern that streams on private lands have less recruitment potential for large wood (> 50 cm) compared to public (state) lands. This pattern can also be seen in preceding three slides.

Tree Tipping as Restoration

NetMap contains a reach scale wood recruitment tool also and it can be used to calculate the effects of thinning and variable width buffers on wood recruitment. In addition, the reach scale tool can also be used to consider how tipping trees into streams during a thinning activity could increase in-stream wood storage beyond that occurring naturally.

Tree tipping in the context of riparian management can be viewed as a form of channel restoration. Tree tipping (say between 10% and 15% of the thinned trees that would normally go to the mill) would markedly increase wood recruitment above that predicted in the previous slides.

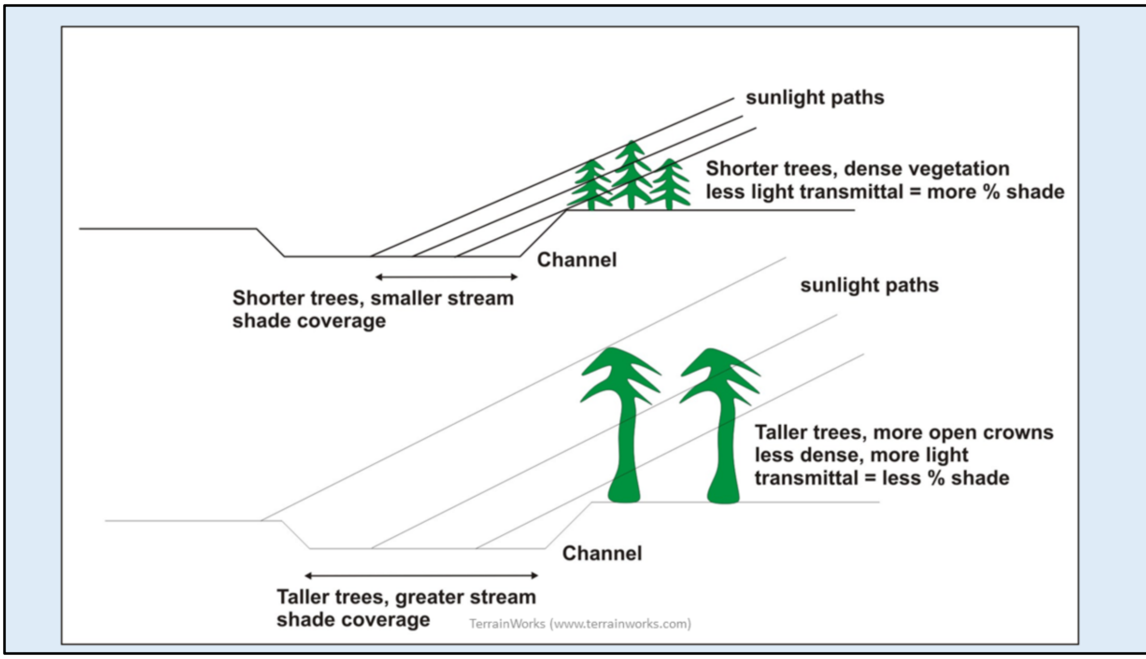
To learn more about NetMap's reach scale wood recruitment tool, including the tree tipping option, see: http://www.terrainworks.com/riparian-management

TerrainWorks (www.terrainworks.com)

Add Shade/Thermal Loading

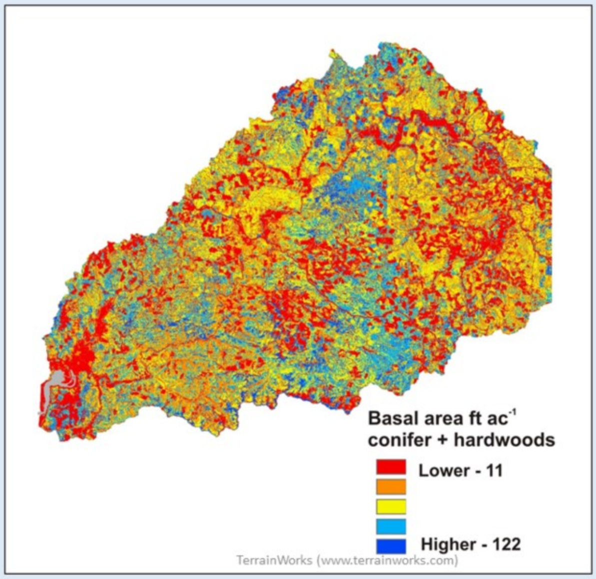
TerrainWorks (www.terrainworks.com)

Shade and thermal loading can be important considerations when planning restoration activities. In particular, shade and thermal loading can be added to the other habitat forming factors to identify the best or optimized areas for targeting riparian and instream restoration.

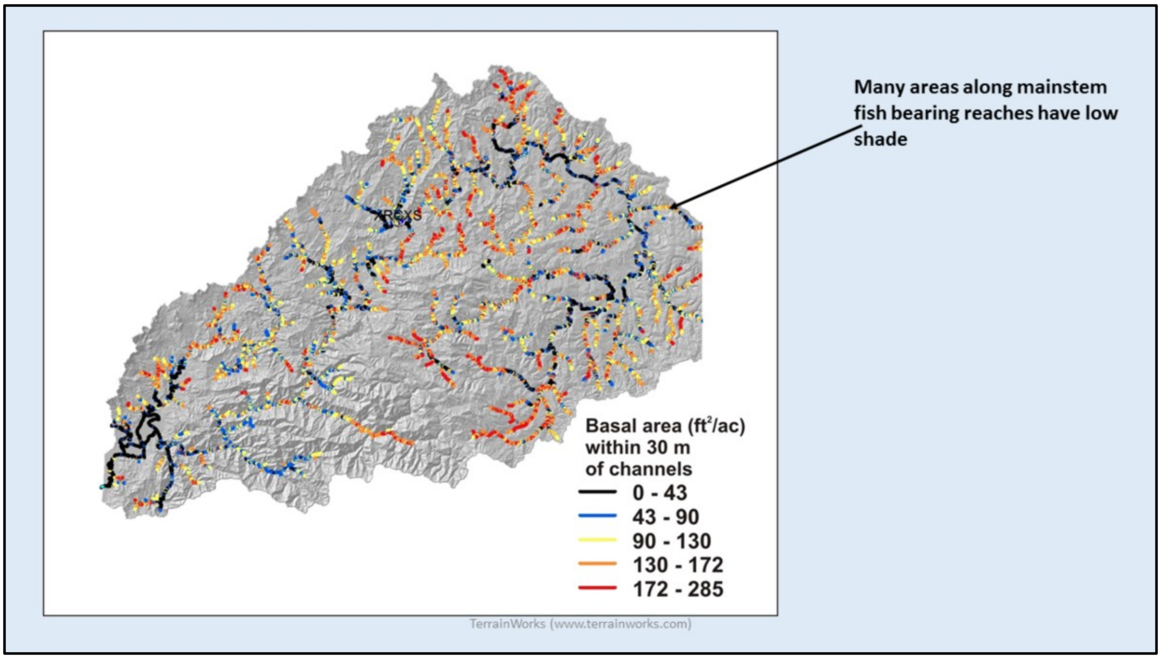


We combined NetMap's physically based thermal loading tool with a model to predict percent shade using basal area and tree height (shade model by Groom et al. 2014). The diagram above illustrates how the shade model works. Percent shade is positively correlated with basal area (think vegetation density) and negatively correlated with tree height (e.g., more light gets through taller trees that have less dense vegetation and more open canopies compared to shorter vegetation with dense vegetation). However, as trees get taller they shade an increasing proportion of the channel width, so taller vegetation equals greater shading also. Keep that in mind as we examine the predictions about how basal area and tree height, combined with natural thermal loading, affect streams in the Nehalem watershed in the next couple slides.

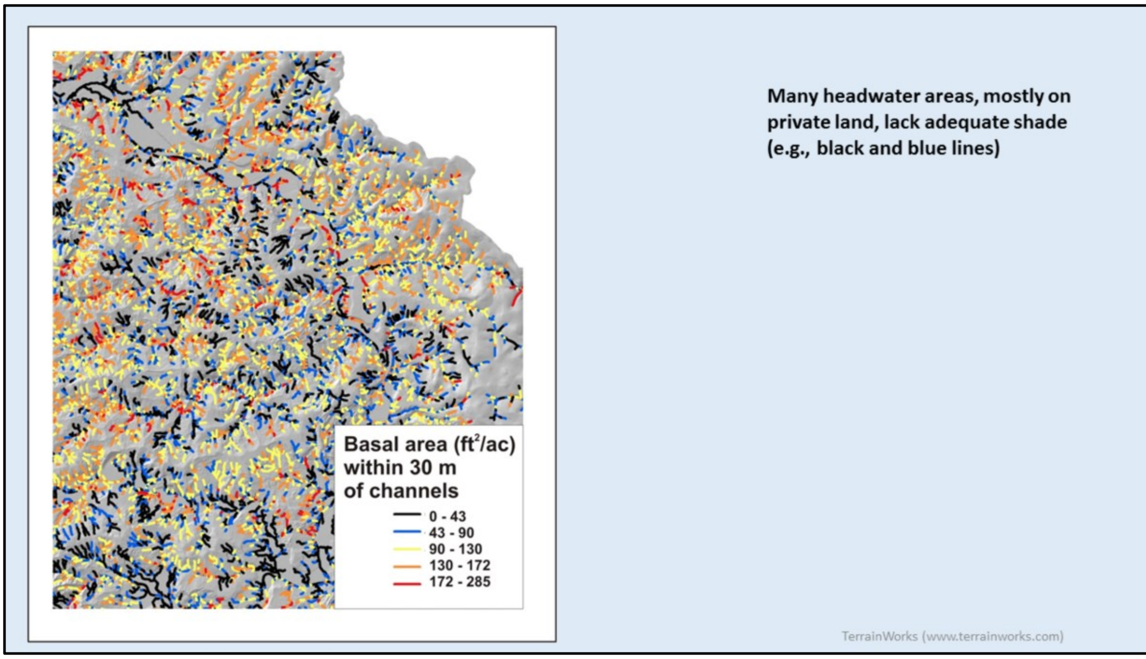
Basal Area (conifers & hardwoods), 30 m each side of channel – represented in stream channels



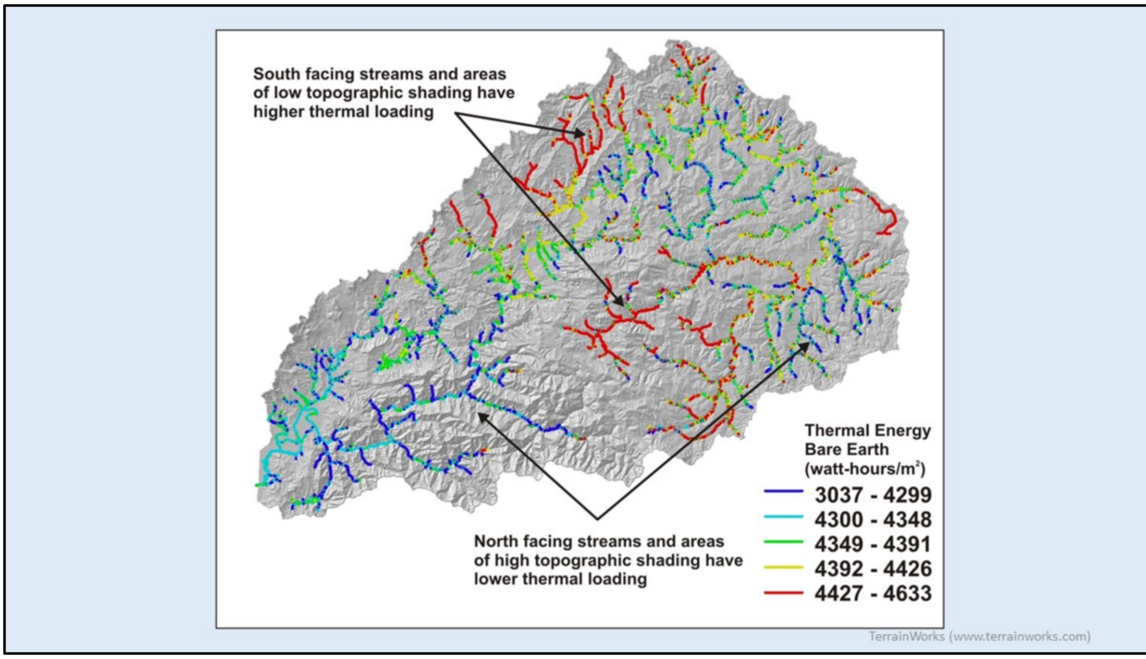
Here is the LEMMA/GNN data on basal area, conifer and hardwoods combined for the Nehalem watershed.



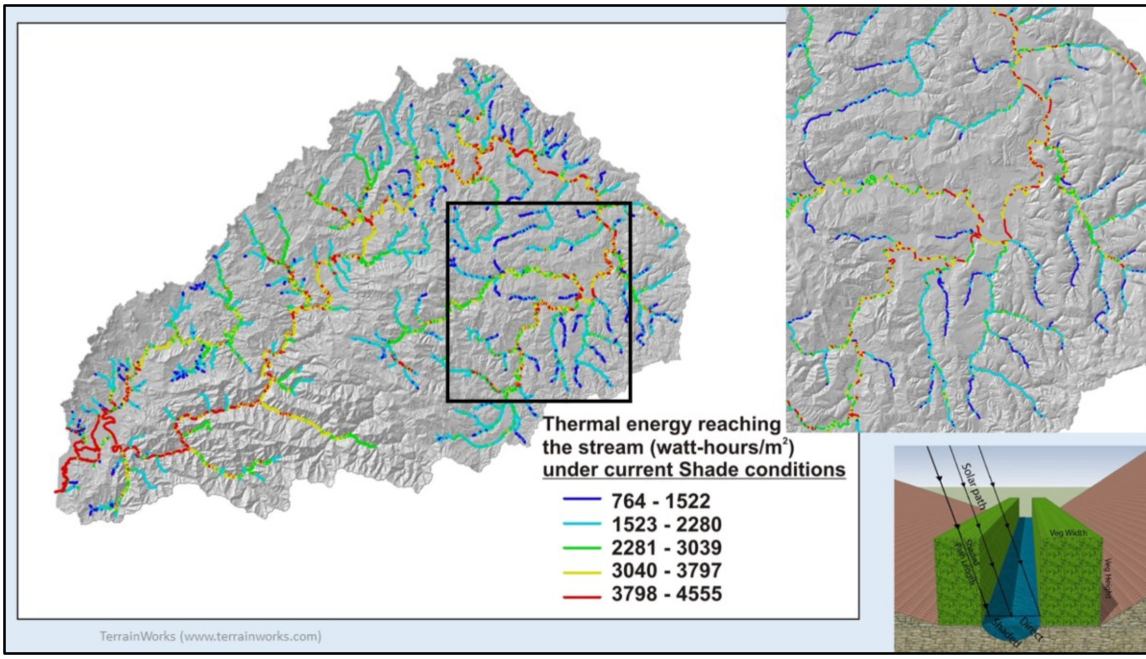
Here is a map of coho salmon bearing streams only revealing areas of high to low shade. Certain areas stand out as having low shade including the larger valley floors that are developed including for agriculture.



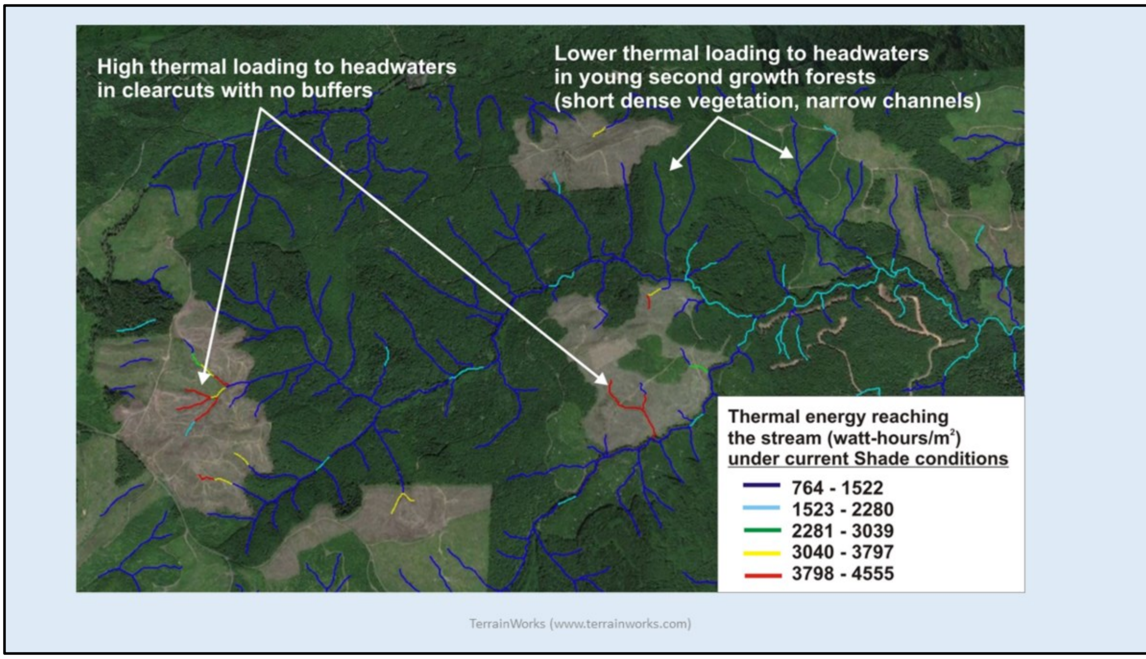
With headwaters included, the shade levels are much lower in many headwater streams, as shown in this slide in the eastern portion of the Nehalem basin, in large part on private forest lands (where no buffers are required).



Bare earth thermal energy loading to coho salmon streams in the Nehalem watershed. Spatial patterns are evident: south facing streams and stream with low topographic shading have higher thermal energy. North facing streams and areas with high topographic shading have lower energy loading.

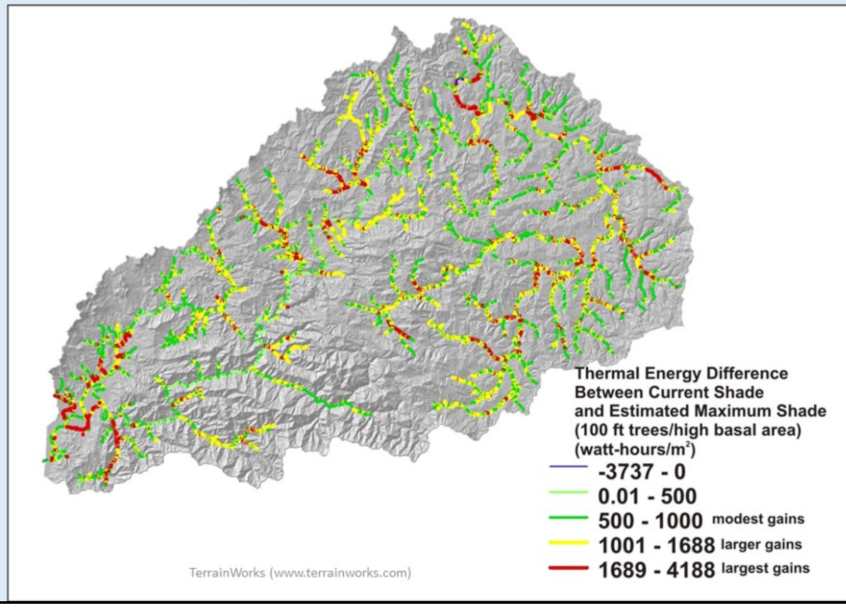


We now evaluate how current shade conditions (basal area combined with tree height) affects thermal loading along streams in the Nehalem watershed. The warmer colors in the map indicate channels that have higher thermal loading due to present day shade, combined with
natural patterns of thermal loading controlled by channel width, orientation, topography and solar angles.

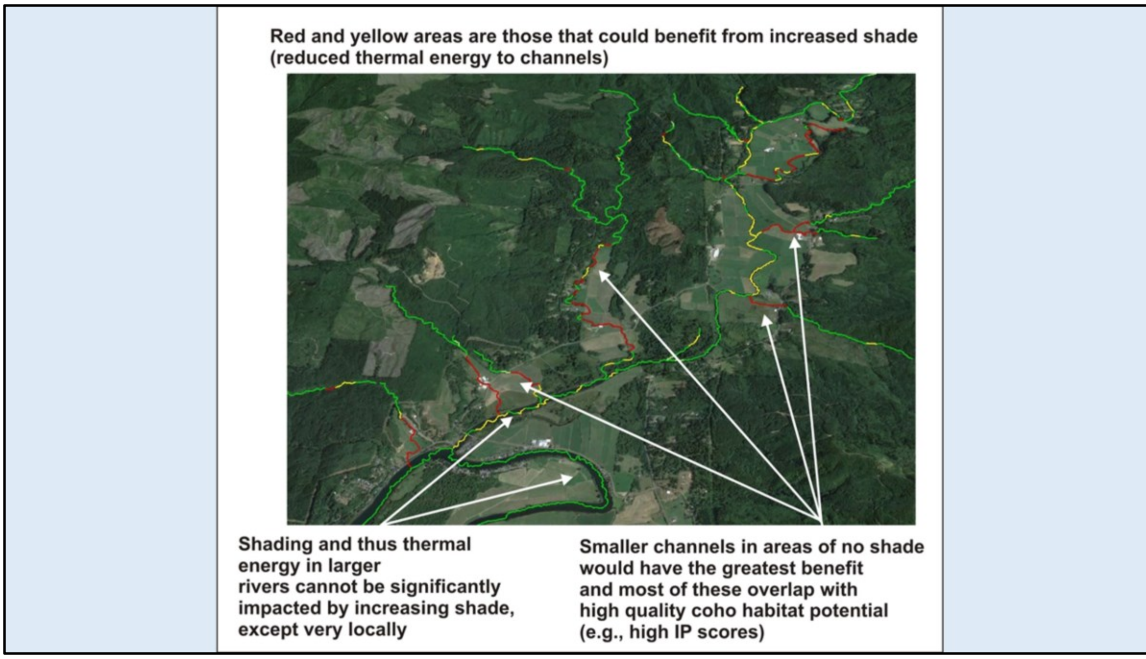


NetMap's predicted current shade-thermal loading conditions including for small headwater channels. Recent clearcuts have the highest thermal loading potential because of the absence of stream side vegetation and buffers. However, younger second growth forests do provide significant shade and thus lower thermal loading, including because of narrow (1-2 m wide) channels. Recall that shading is positively associated with basal area but negatively correlated with tree height (see slide 52).

Where is increased shade needed most?



We can estimate, based on Nehalem specific vegetation conditions, a likely maximum shade condition, combining basal area and tree height. A maximum shade condition is calculated using a high basal area (122) and a 100 ft tree height. The current shade condition (previous) slide is subtracted from that. The result is a map that shows where increasing shade by vegetation manipulation would have the largest potential benefit on water temperatures. The yellow and red areas in particular may be areas where increasing shade would be an improvement. See also next slide.



As would be expected, small high value coho streams located on floodplains and terraces, but under current agriculture, are most sensitive to current low shade levels compared to larger rivers where shade is proportionally less important in reducing thermal loading.

Calculating Potential Thermal Refugia and Thermal Hot Spots
Four types:

1) **Along channel (reach scale) thermal refugia created by a combination of natural landscape controls on thermal load (topographic shading, stream size & orientation, and current stream side vegetation conditions;**

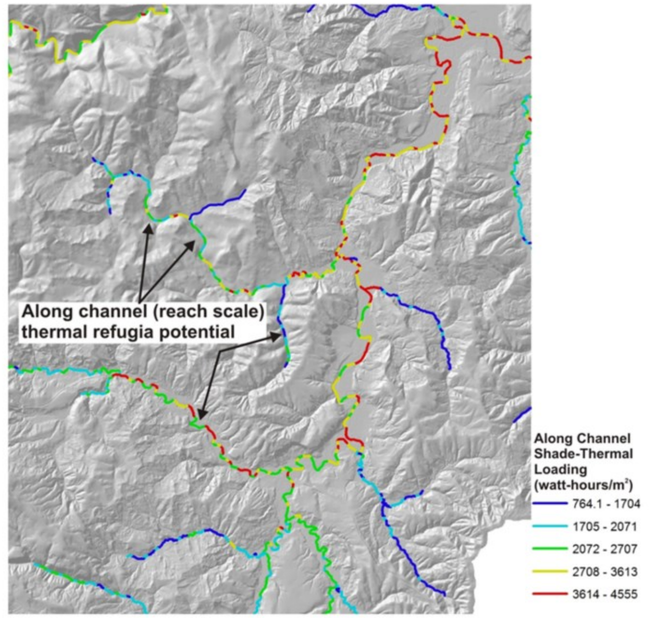
2) **Tributary scale thermal refugia, same as #1 but aggregated (averaged) over individual tributaries;**

3) **Tributary confluences that show the relationship between accumulated landscape thermal load plus shade in mainstem channels compared to intersecting tributaries (provisional cold and hot spots)**

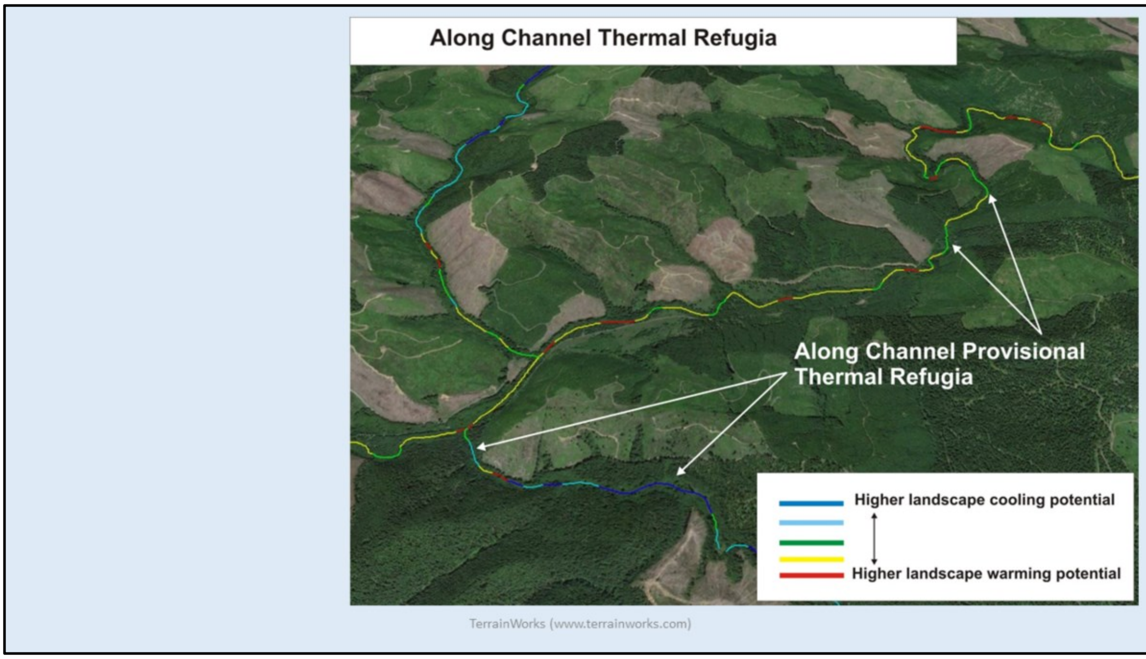
4) **Downstream spatial variation in floodplain magnitude (widths). Floodplain narrowing enhances upwelling of cooler hyporheic water.**

NetMap contains a tool for predicting provisional thermal refugia in streams and rivers including related to tributary confluences and floodplains. See next couple of slides.

Along channel thermal refugia

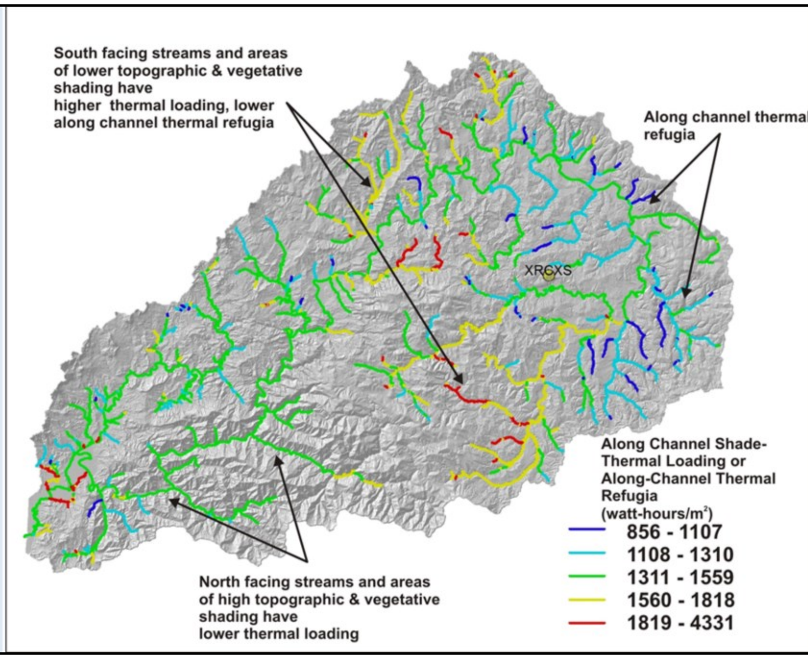


Based on natural controls on thermal loading (topographic shading, channel width, orientation and solar angles) and on current shade conditions along streams (basal area and tree height), NetMap can be used to predict provisional areas of thermal refugia, and alternatively, areas of warmer water landscape conditions. And see next slide.



Examining reach scale (100 m) spatial patterns of the combined effects of current shade (tree height and basal area) and landscape controls on thermal energy (topographic shading, stream orientation, stream width, solar angle) can be used to consider “along-channel thermal refugia” potential. Note that water temperature mixing length is important and is not considered here. In other words, the length scale of the changing patterns matter with longer reaches being more potentially effective compared to shorter reaches.

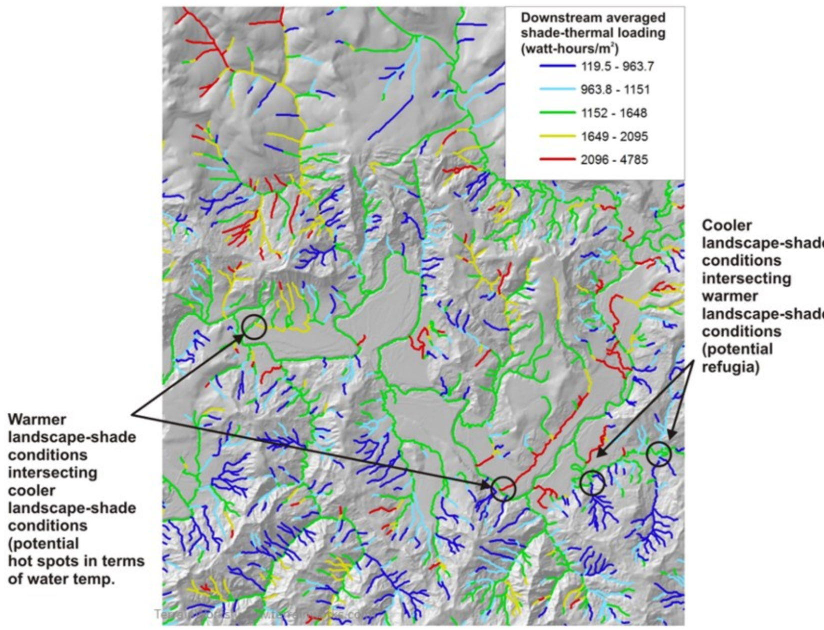
Tributary scale thermal refugia



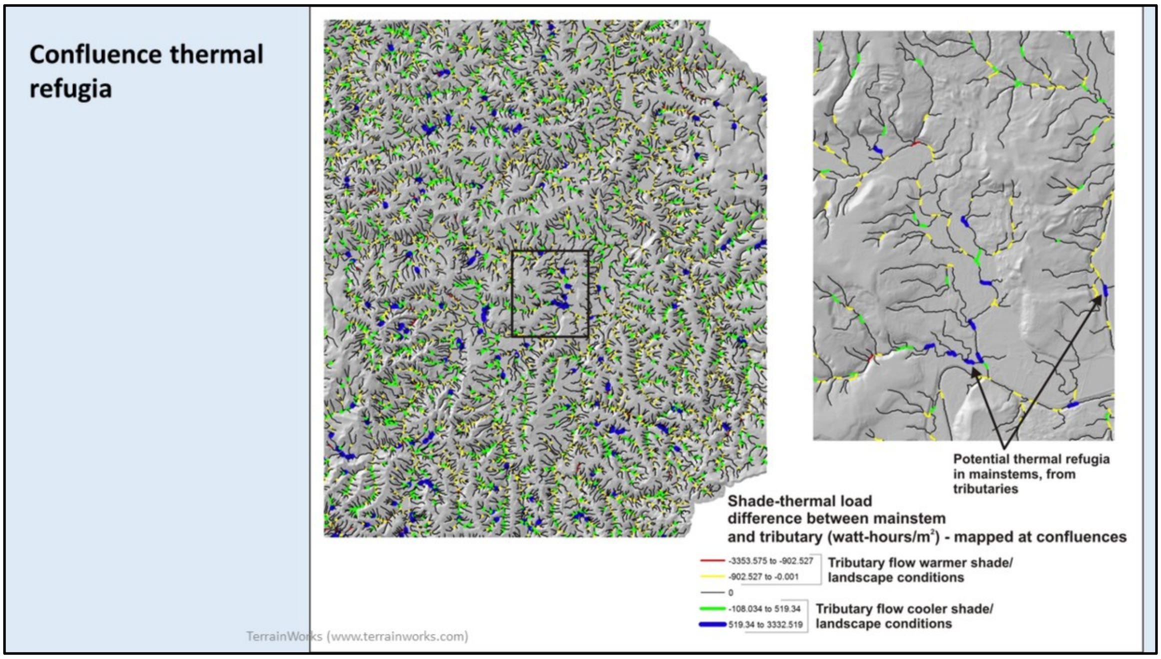
TerrainWorks (www.terrainworks.com)

The combined condition of current shade (tree height and basal area) and landscape controls on thermal energy (topographic shading, stream orientation, stream width, solar angle) can be aggregated downstream producing tributary basin averages. This results in tributary scale predictions of thermal refugia.

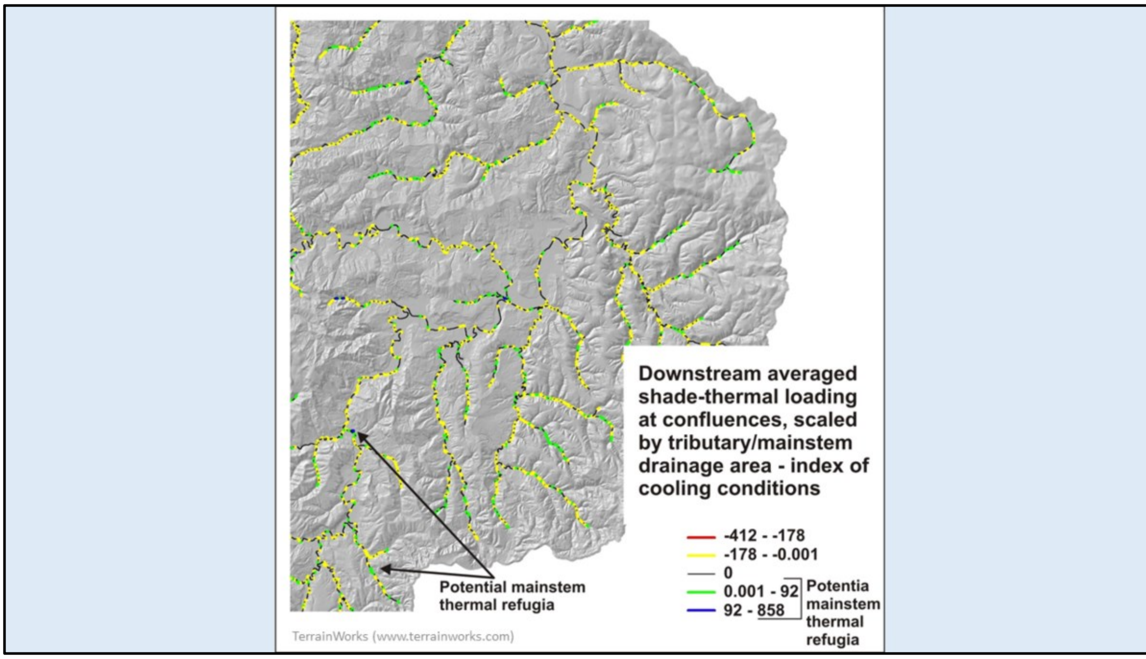
Thermal relationship between tributaries and mainstem channels



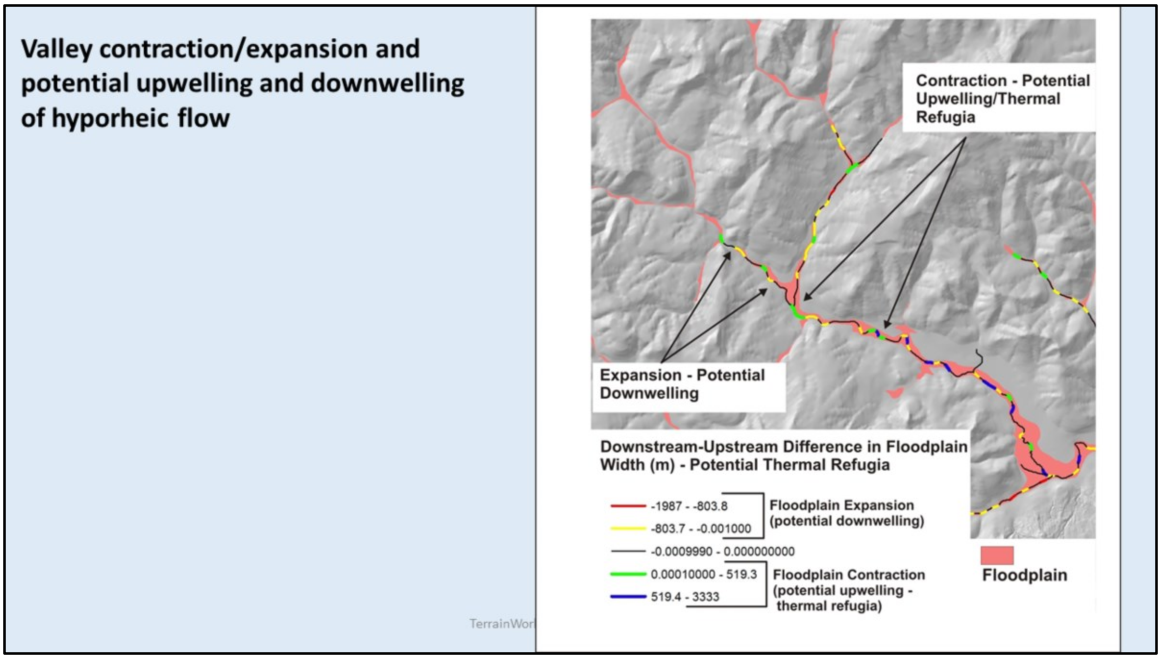
Another way to examine tributary scale thermal energy conditions is to view them at confluence locations (tributary locations with mainstem channels). Juxtapositions between tributaries and mainstems can be used to examine areas of provisional cold and warmer water landscape conditions and whether tributary mouths might be functioning as thermal refugia from the perspective of warmer mainstem conditions.



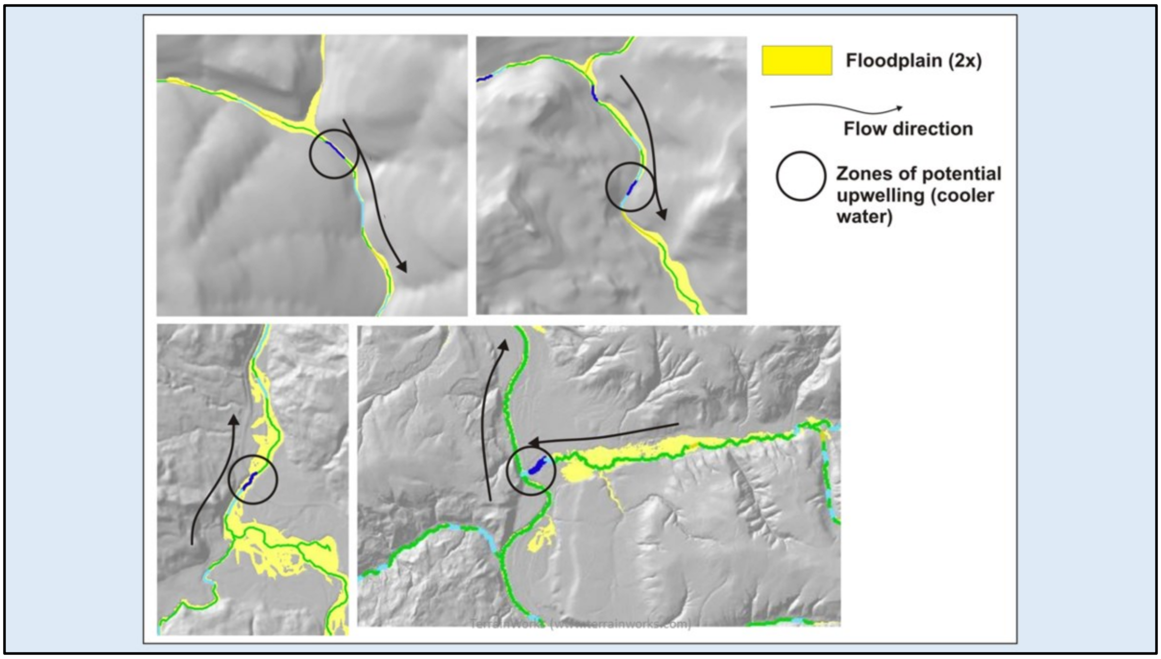
Another type of thermal refugia occurs in mainstem channels at tributary confluence locations. In this calculation, the aggregated landscape and shade controls on thermal loading of tributaries are compared to the aggregated landscape and shade controls on thermal loading of mainstems (e.g., mainstem minus tributaries); in the legend positive numbers = potentially cooler conditions at confluences; negative values = potentially warmer conditions at confluences. Hence, in the maps, greens and blues are provisional thermal refugia at confluences.



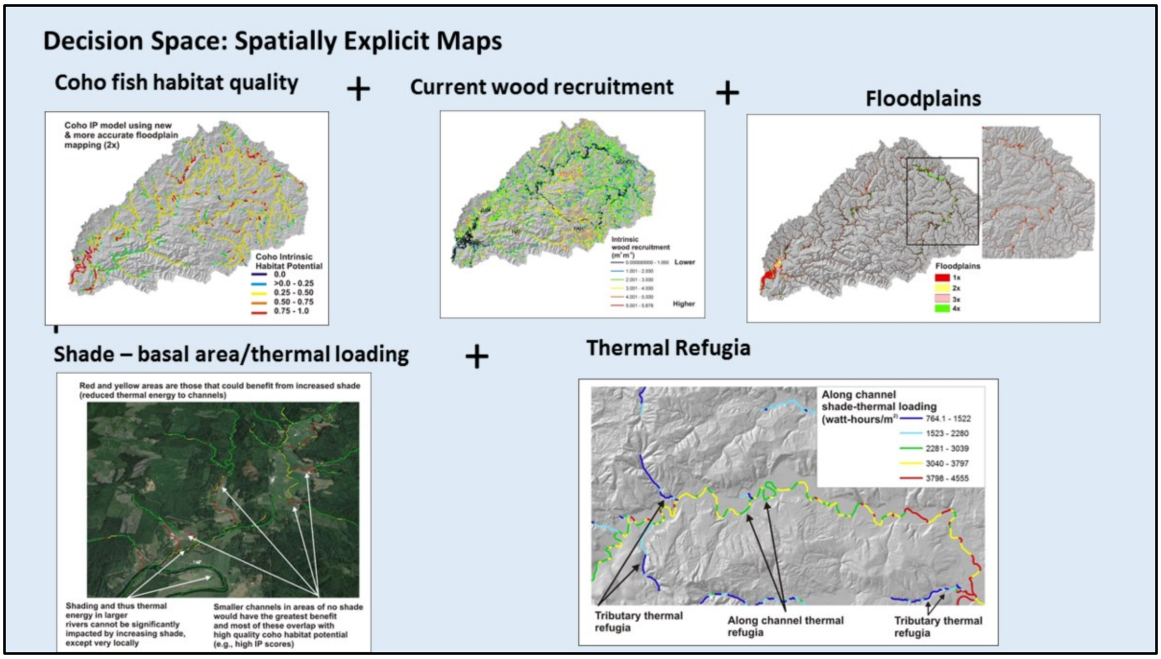
The volume of flow from tributaries is important when considering whether tributary landscape and shade conditions can provide cooler water to mainstem channels. Here, we take the downstream averaged shade-thermal loading conditions (previous slide) and weight them by the ratio of tributary drainage area to mainstem drainage area, to provide a measure of tributary size (and flow) in association with landscape thermal conditions.



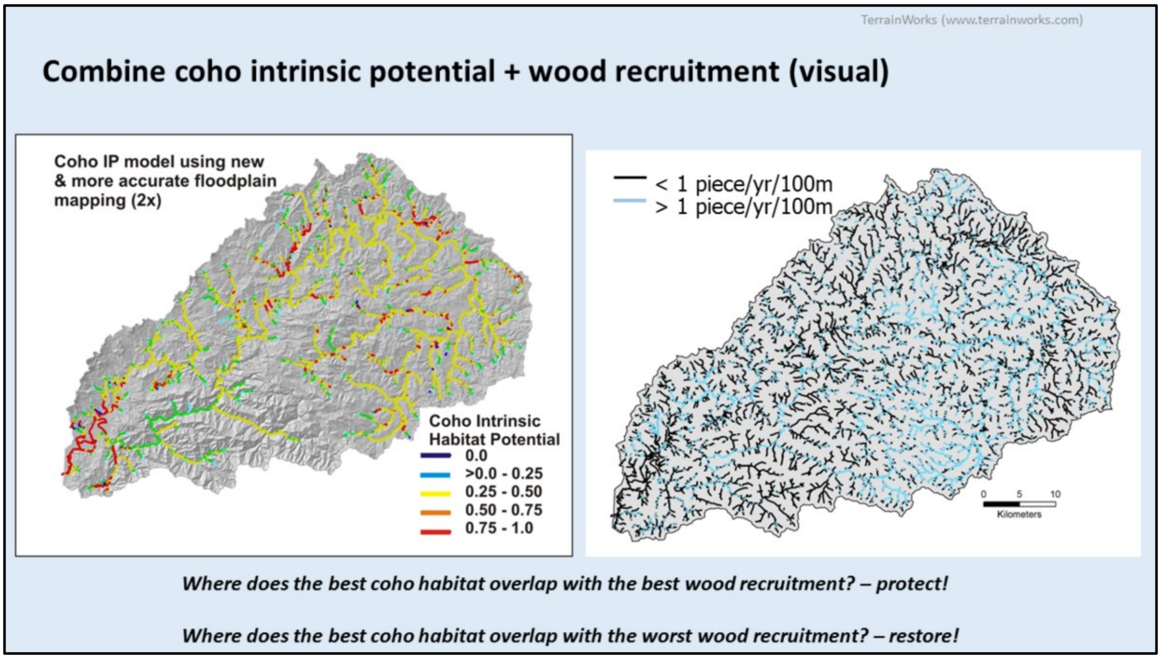
The fourth type of potential thermal refugia is where floodplains (or terraces or higher elevation valley floors) contract
abruptly downstream, often causing hyporheic upwelling of cooler water. NetMap's thermal refugia tool calculates this type using reach to reach downstream changes in floodplain width, as shown in this slide for areas in the Nehalem watershed.



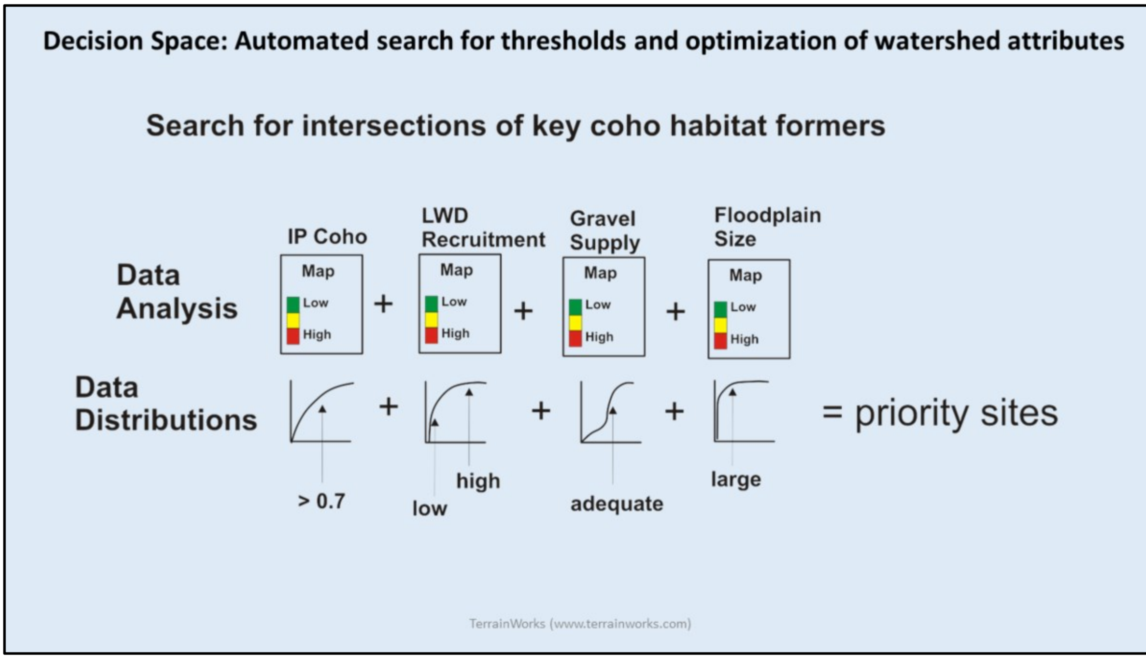
Another example of identifying potential areas of hyporheic upwelling, as thermal refugia.



Recall one of the restoration planning decision spaces, involving overlaying maps of habitat forming processes. The issue of gravel supply has been omitted in the current presentation but see PPT addendum (at the end of this presentation) to review results from the sediment (gravel) supply analysis.

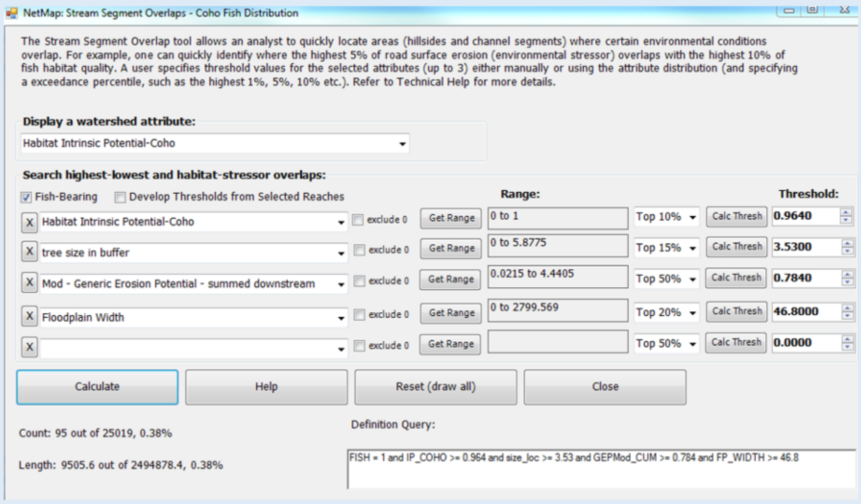


Decision Space: combine coho intrinsic potential scores with current, in-stream wood recruitment. Visually identify areas of overlap between the two. In areas of the highest IP scores and the highest wood recruitment, enhance protection. In areas of highest IP scores and lowest wood recruitment, prioritize for restoration activities (instream structures and or riparian restoration).



A second type of restoration planning decision space: using data distributions for all relevant habitat forming processes, select habitat condition thresholds for each of them and let NetMap quickly search for and locate spatial intersections between the various attributes. For example, where does the highest 10% of coho quality habitats (IP) intersect with the lowest wood recruitment potential and the widest floodplains? How many sites are there and where are they located. Use these data to prioritize restoration. Some examples follow.

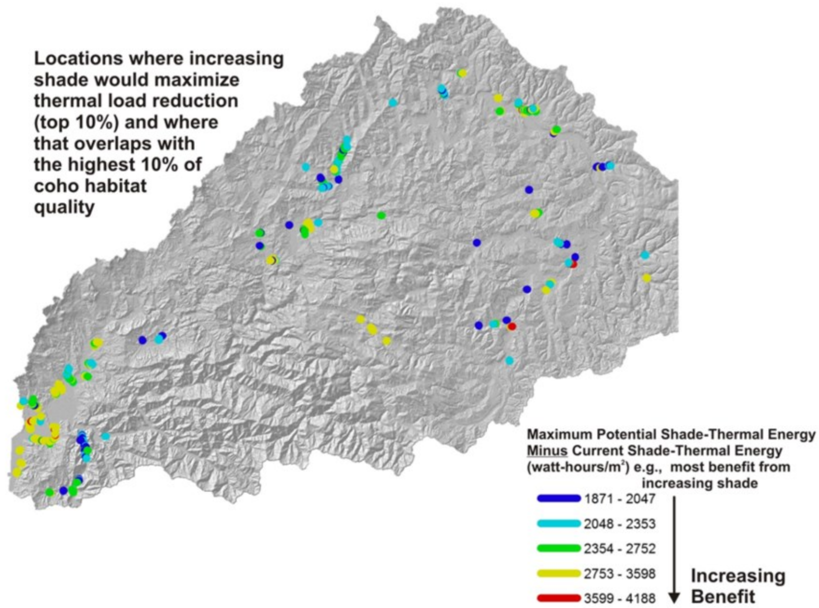
NetMap Tool to Search for Optimizations



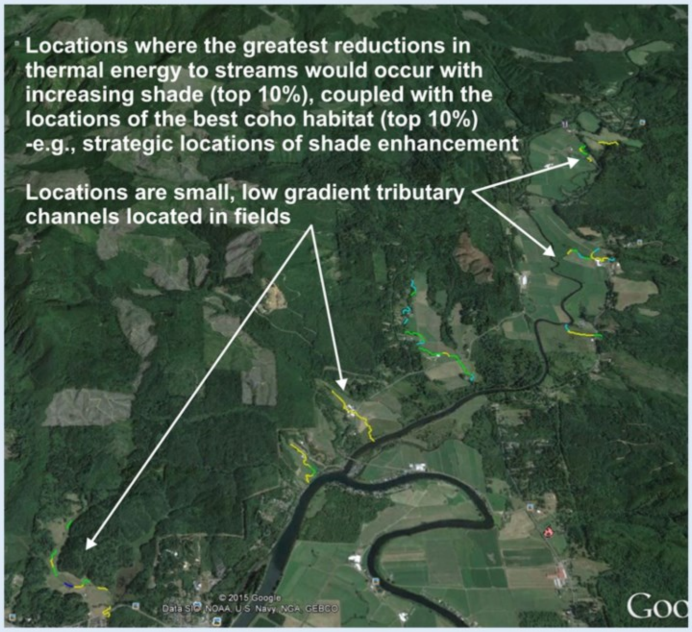
TerrainWorks (www.terrainworks.com)

NetMap contains a tool, that works with its virtual watershed like the Nehalem, to quickly locate intersections among habitat forming processes to help prioritize restoration site selection and monitoring. For more details on this tool, see: http://www.netmaptools.org/Pages/NetMapHelp/overlap_tool___reaches.htm

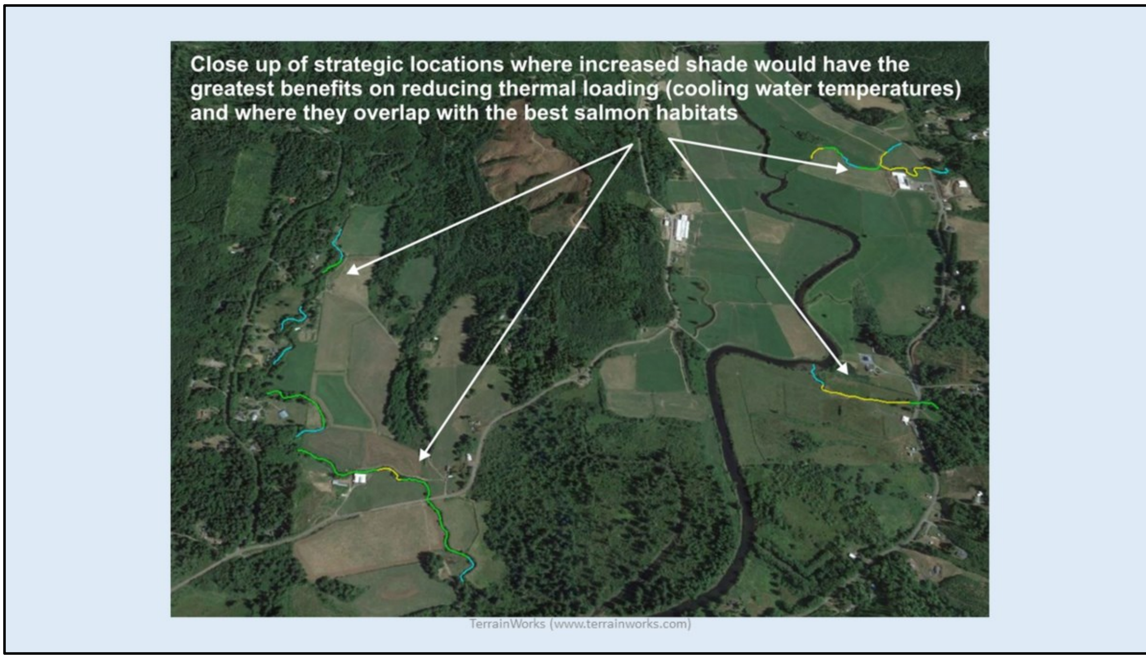
Identify strategic locations where increasing shade would have the greatest benefits



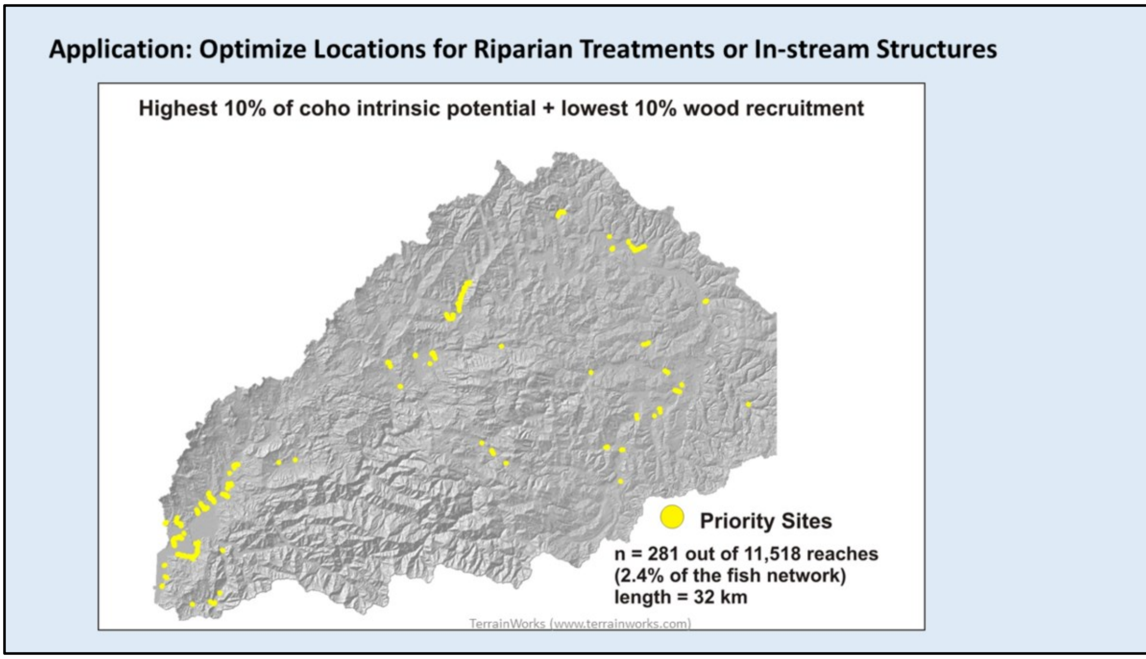
Use NetMap's overlap tool to quickly identify the locations where shade would have the greatest effect at reducing thermal energy to streams and where those locations overlap with the best fish habitat.



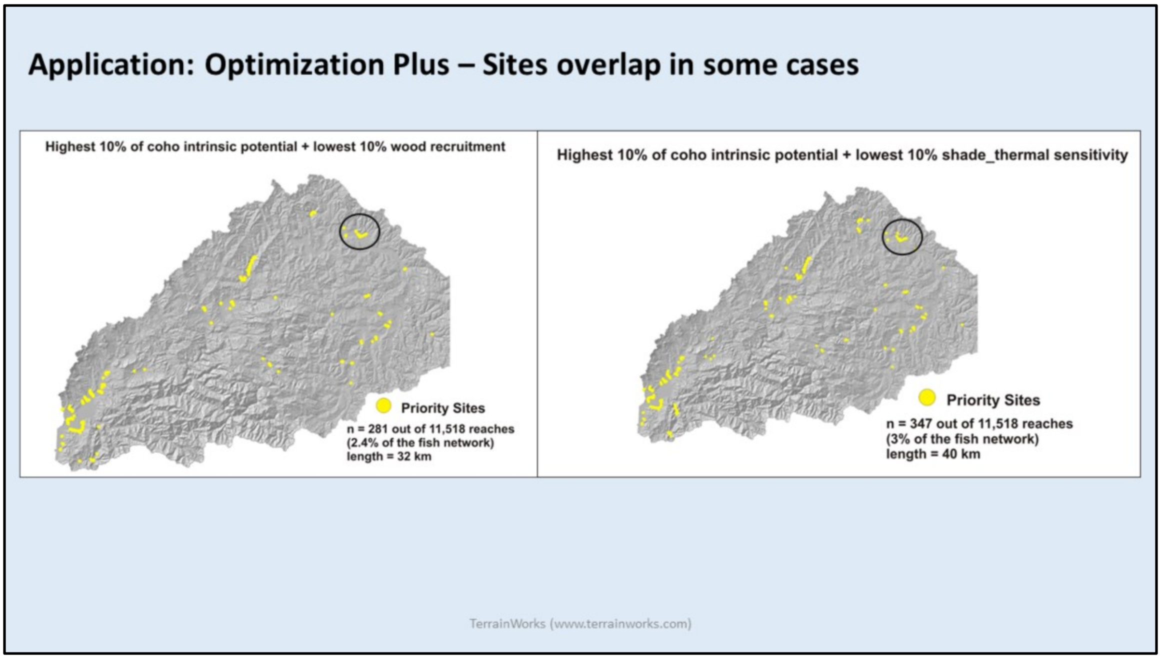
Export results to Google Earth



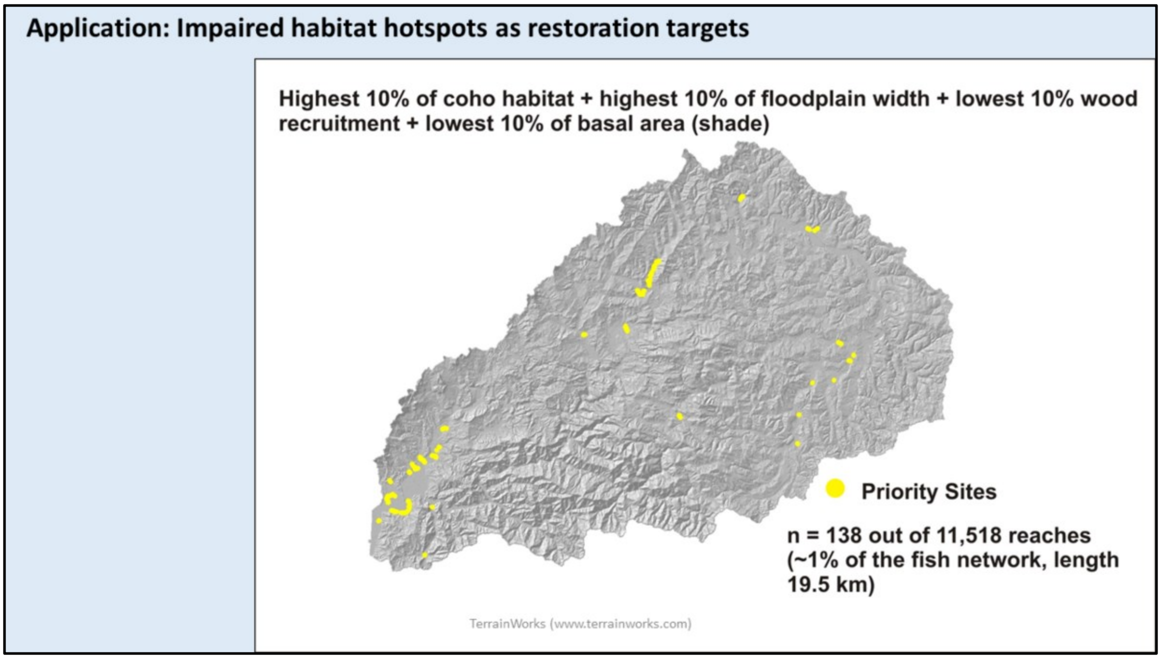
Small streams that have high coho habitat potential and low current shade would benefit most by shade enhancement



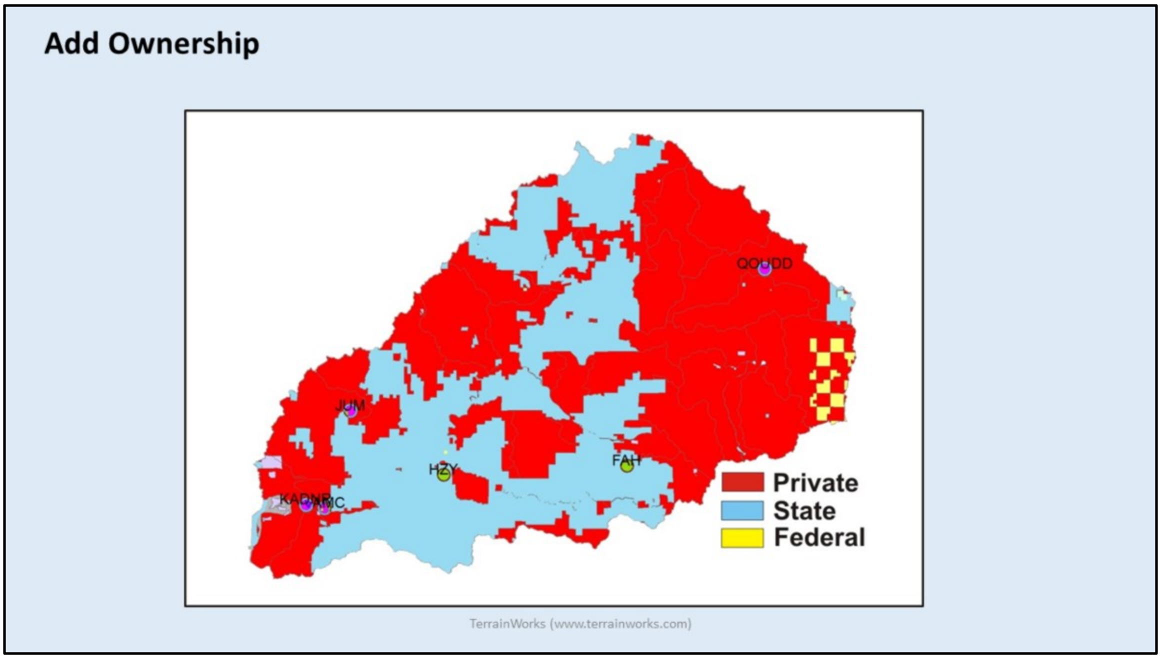
Using NetMap's tool, we quickly identified the locations where the highest 10% of coho habitat quality (IP) overlaps with the lowest 10% of wood recruitment. 281 sites were identified out of the total of 11,518 reaches in the virtual watershed (2.4% of the fish bearing network, with a total length of 32 km). Analysts, using the tool (previous slide), can change the threshold values (e.g., top 5%).



Sometimes, priority sites will overlap, yielding a bigger bang for your buck! Here there is commensurability among the best coho habitats (IP) and low wood recruitment and shade-thermal sensitivity. Use these types of maps to prioritize restoration actions.



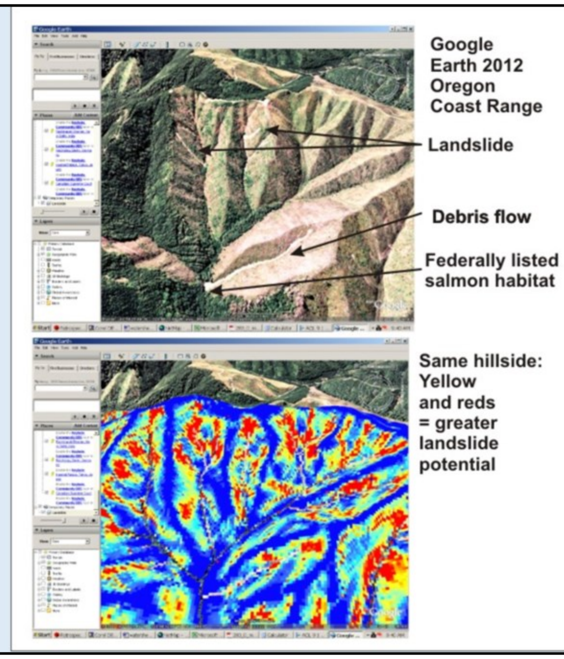
In NetMap, you can search for five levels of intersections or overlaps among habitat forming conditions (or lack thereof). This example shows how four factors were overlaid: highest 10% of coho habitat, highest 10% of floodplain width, lowest 10% of in-stream wood recruitment and the lowest 10% of shade, conditioned by thermal sensitivity. Only about 1% of the fish bearing network meets these criteria; use this type of information to inform restoration planning.



Ownership (federal, state, local, private) can be an important determinant in selecting restoration sites. See how ownership varies across the

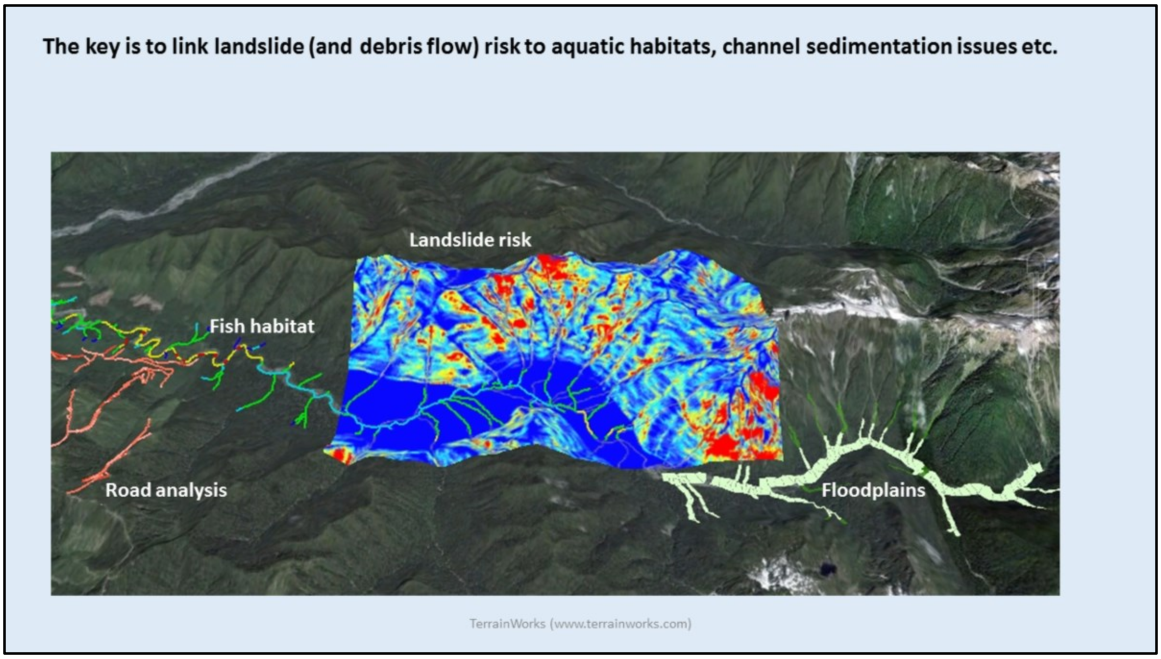
Other attributes to consider: landslide potential

highest resolution DEMs + latest models

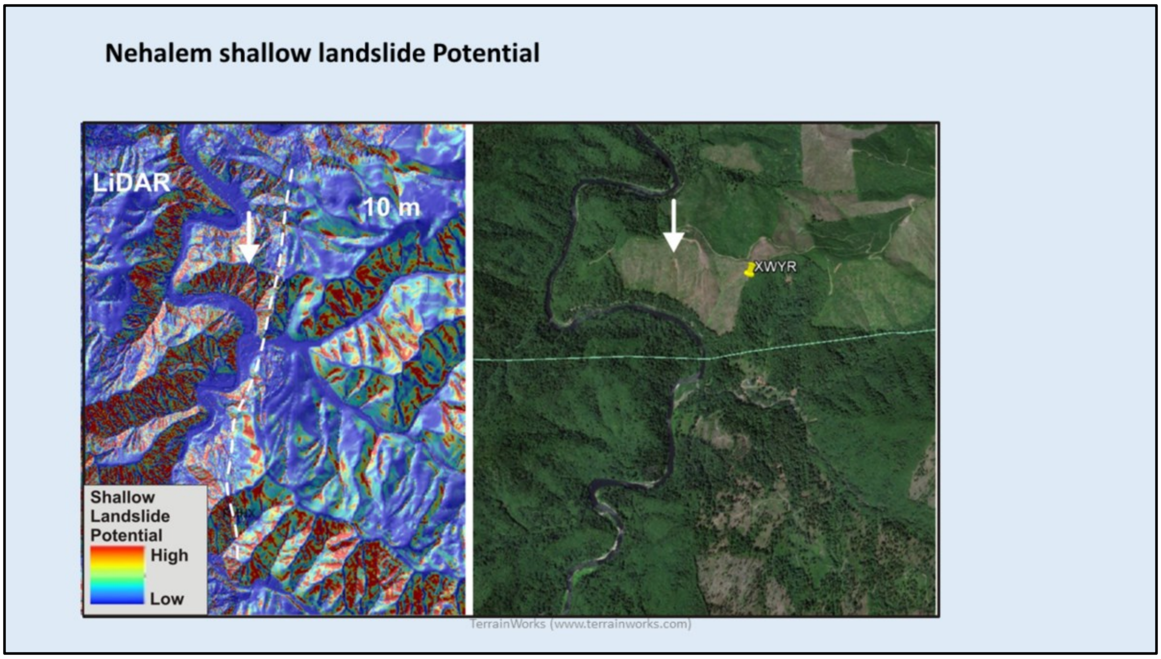


TerrainWorks (www.terrainworks.com)

Another important factor to consider in watershed restoration is landslide potential. Although not considered a restoration priority per se, information on landslide potential could be used in watershed management planning more generally, or restoration planning more specifically, about where erosion risk is the highest and what types of land uses can contribute to it, such as roads. The image above is from the Oregon Coast Range.



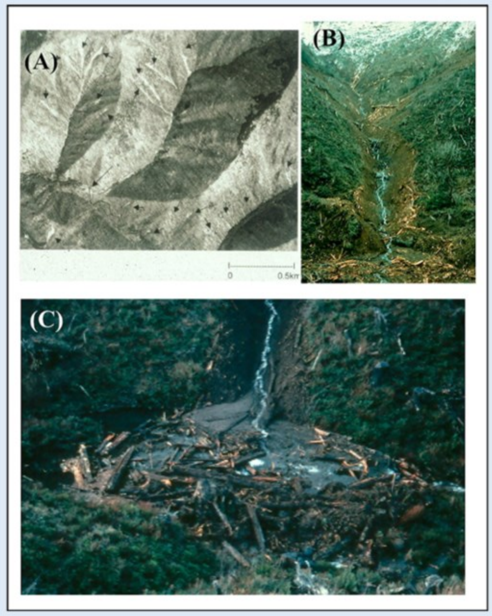
The slide shows several types of NetMap outputs including landslide risk, fish habitats (steelhead IP), floodplains and road erosion potential. The key is to link these to identify areas of concern, including for prioritizing watershed restoration.



Here is an example of how shallow landslide potential is mapped using either 10 m or LiDAR DEMs in the Nehalem watershed. The LiDAR DEM when used with shallow landslide models provide a much higher spatial resolution, although the 10 m does an adequate job.

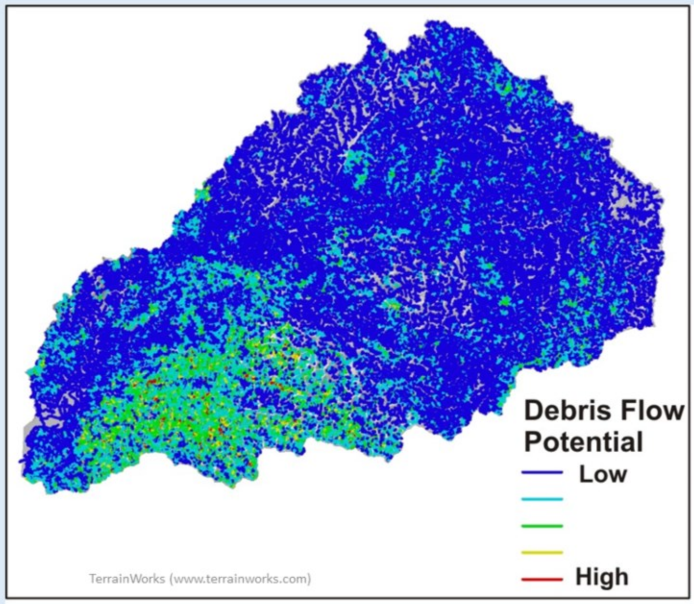
Debris flows –

impact potential but also upslope sources of large wood to streams



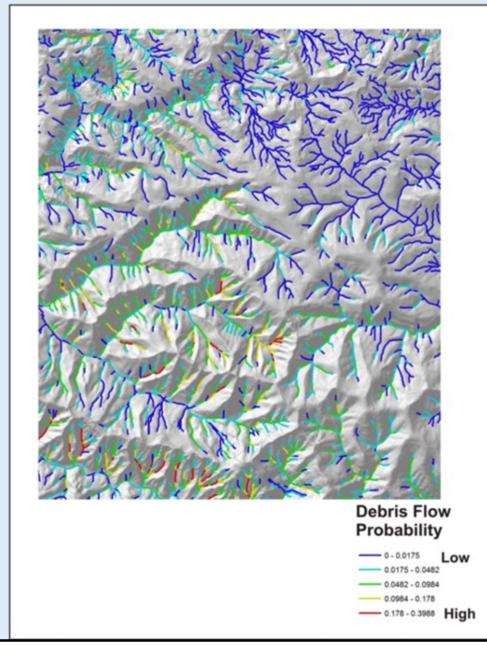
Landslides often transition into debris flows that move through steep and confined headwater streams. Debris flows can pose a risk to fisheries but they can also be sources of large woody debris to streams, that can enhance fish habitat. For example, restoration could target the leaving of buffer strips along certain headwater streams to ensure the long term supply of large wood to streams; in many areas of the Oregon Coast Range, debris flow related upslope sources of wood are the dominant wood supply.

ADD debris flows



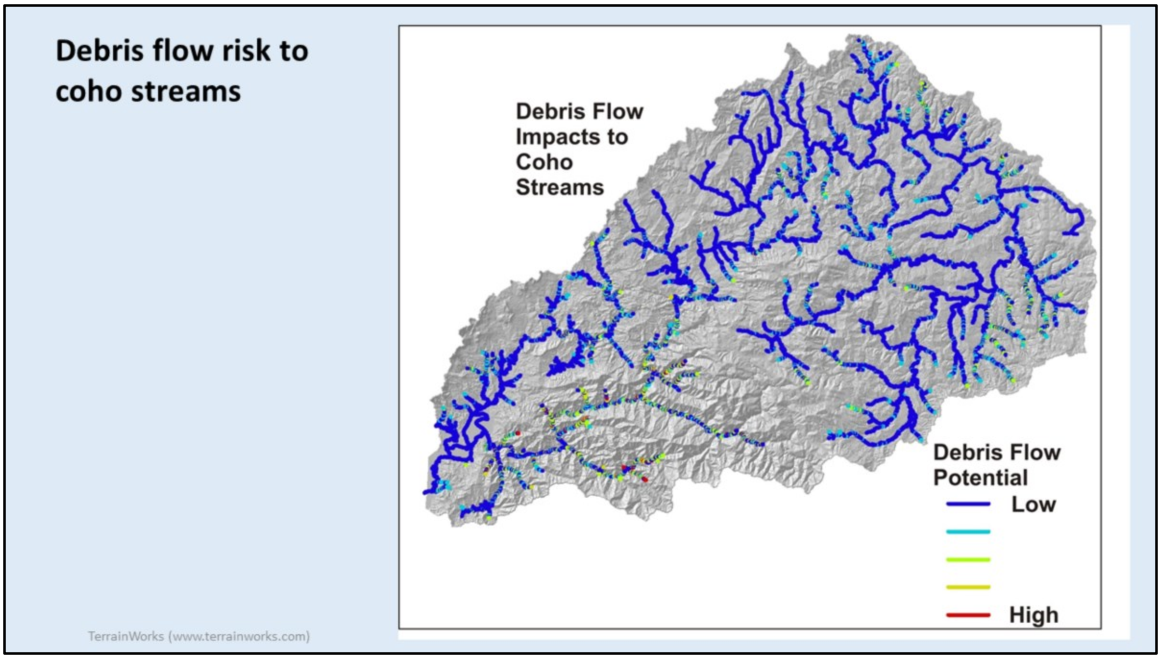
The Nehalem watershed has a low debris flow potential overall, since the relatively weak bedrock (mudstone) leads to lower relief and less steep hillsides. The main area of high debris flow risk located in the southwestern area of the basin in an area of mechanically stronger basalt rocks, that lead to higher relief hillsides that are steeper.

Debris flows –
close up

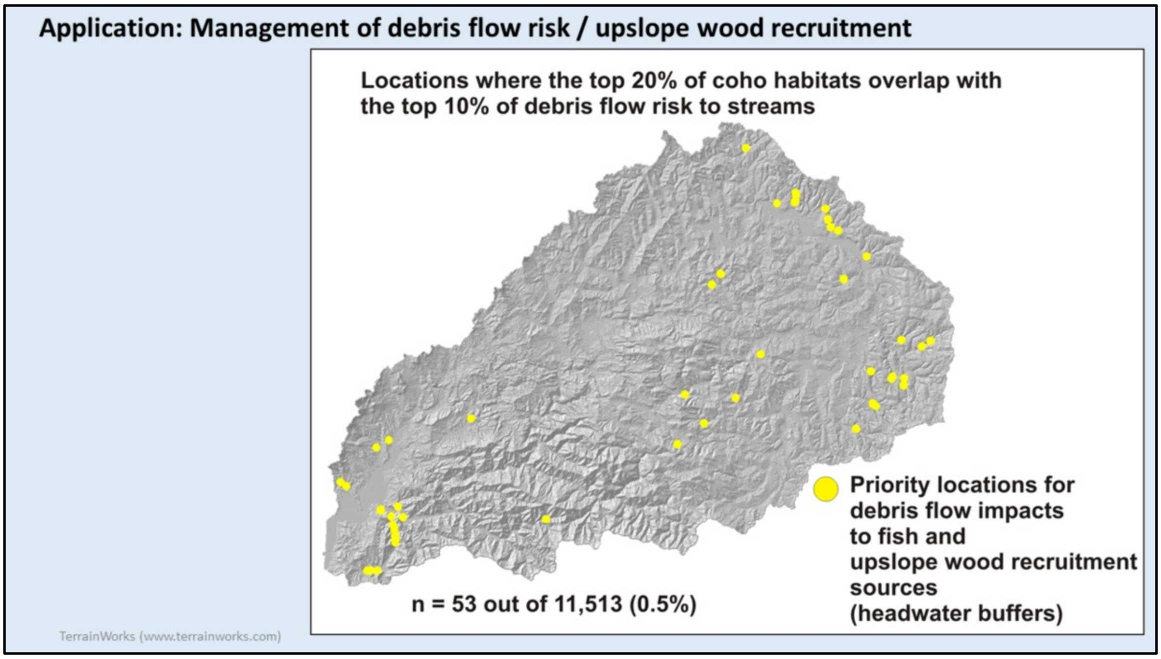


TerrainWorks (www.terrainworks.com)

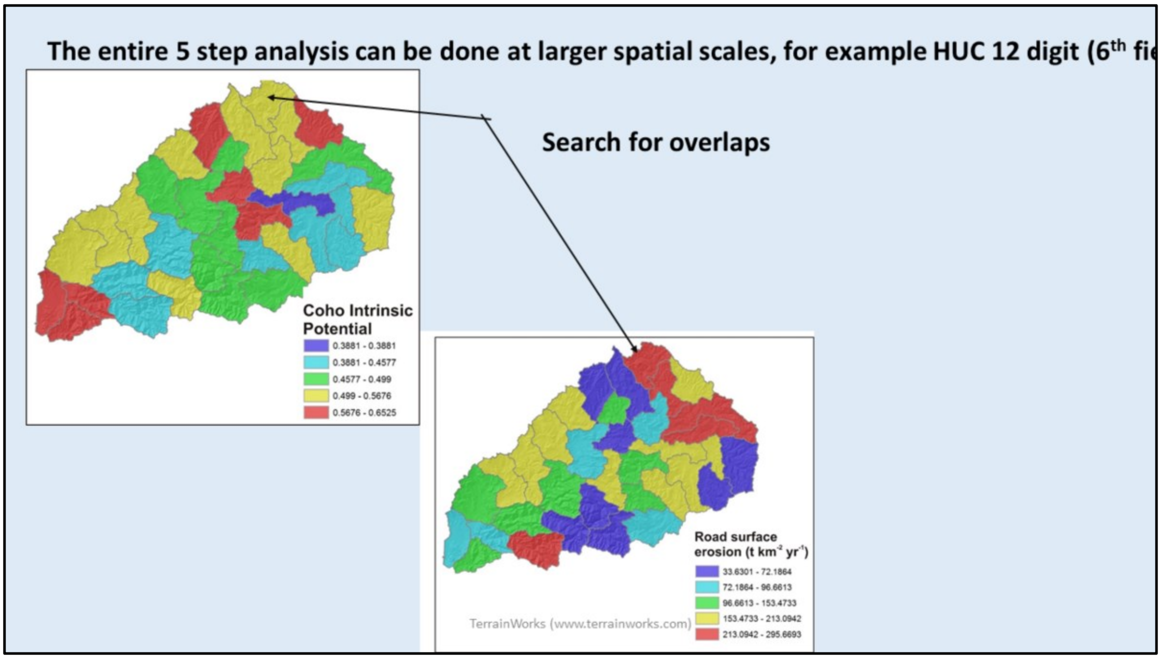
Here is a close up view of debris flow potential in headwater streams in the Nehalem watershed. You can see the difference between the higher relief and steep basalt rocks (towards the southwest) and the lower relief and lower gradient hillsides (mudstone) to the northwest.



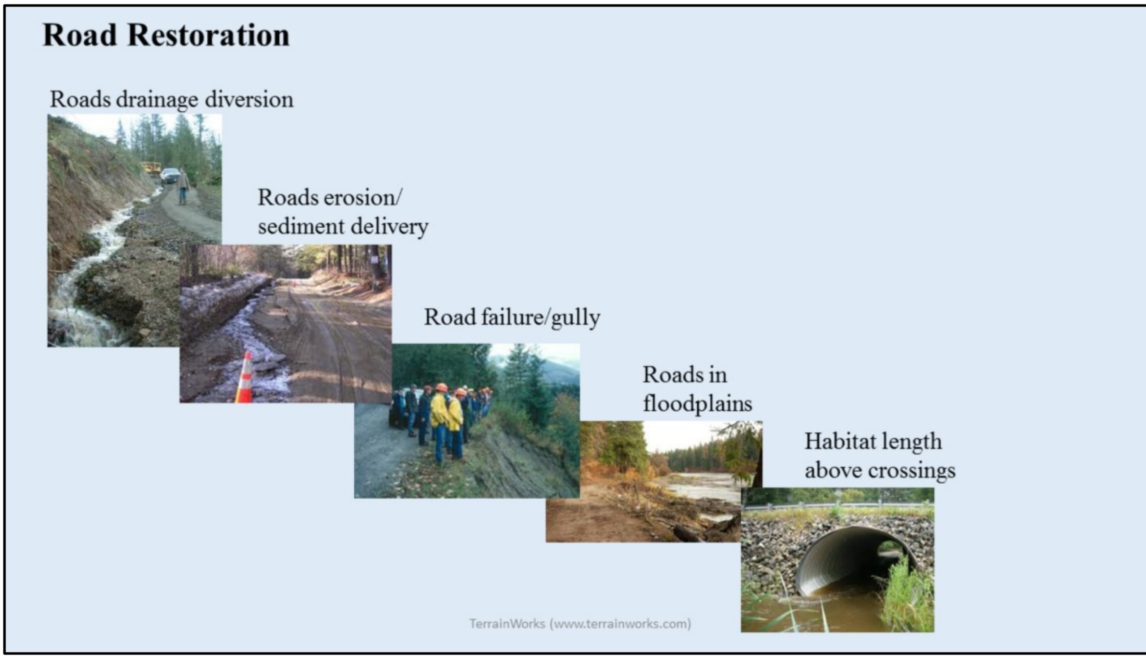
A key aspect involving forest management, watershed management and restoration is whether debris flow impacts can overlap high quality fish (coho) habitats. In NetMap, this is a quick analysis and shown in this slide is debris flow risk to coho habitat streams. The source areas of this risk could be used to identify restoration opportunities or hillsides that require additional protections.



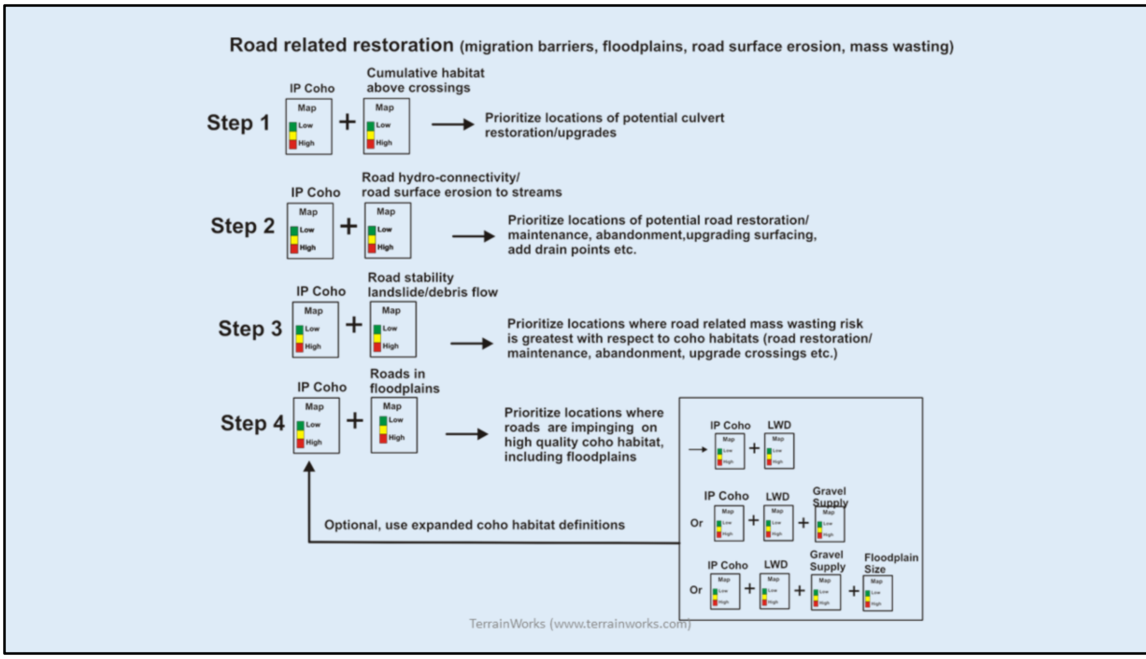
When considering the importance of debris flows, either as an impact or as a source of upslope large wood, to fish habitats, and specifically to coho habitats in the Nehalem, NetMap is used to quickly identify locations where the top 20% of coho quality habitats overlap with the top 10% of debris flow risk. Sites are shown in yellow. Only 0.5% of stream reaches are identified, indicating the relatively low susceptibility of fish habitat to debris flows in the Nehalem system.



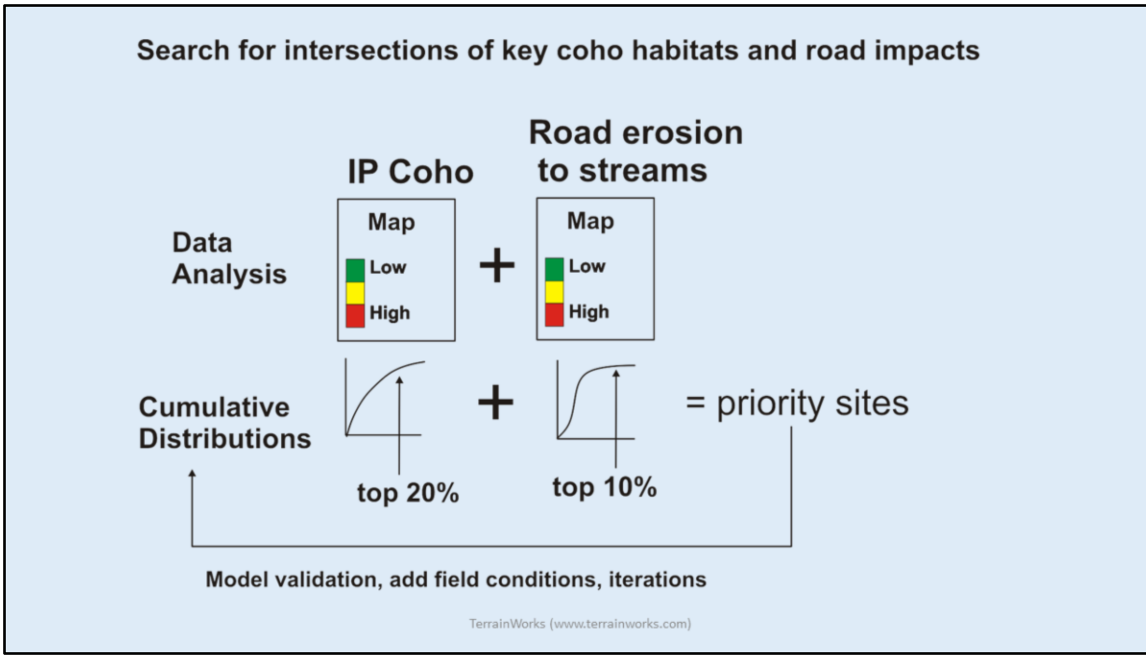
Throughout this pilot Nehalem restoration planning project and powerpoint presentation, analyses were conducted at the scale of individual stream reaches and floodplains (100 m reaches) and slices of hillsides (approx. 0.1 km^2). However, in NetMap all watershed attributes including all those discussed in the PPT, can be summarized at the scale of subbasins, illustrated here using HUC 6^{th} field (12 digit) hydrologic unit code basins. Thus, restoration activities could be evaluated at this scale (approximately 10,000 to 15,000 acres) and then other tools, as outlined above, could be used to drill down to the scale of individual channel reaches and hillsides.



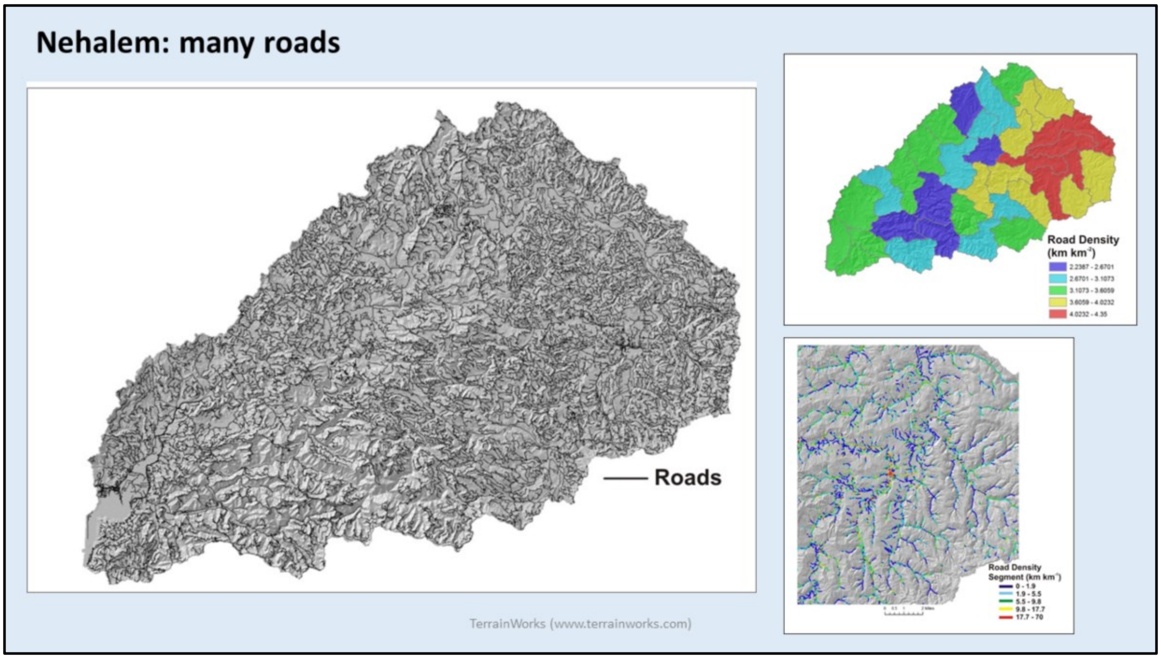
Watershed restoration activities can include road upgrades, maintenance and abandonment, as well as new construction. In NetMap and as applied in the Nehalem, road restoration can address: 1) drainage diversion, 2) road erosion and sediment delivery to streams, 3) road failure and gully potential, 5) roads in floodplains and 6) habitat length above road-stream crossings.



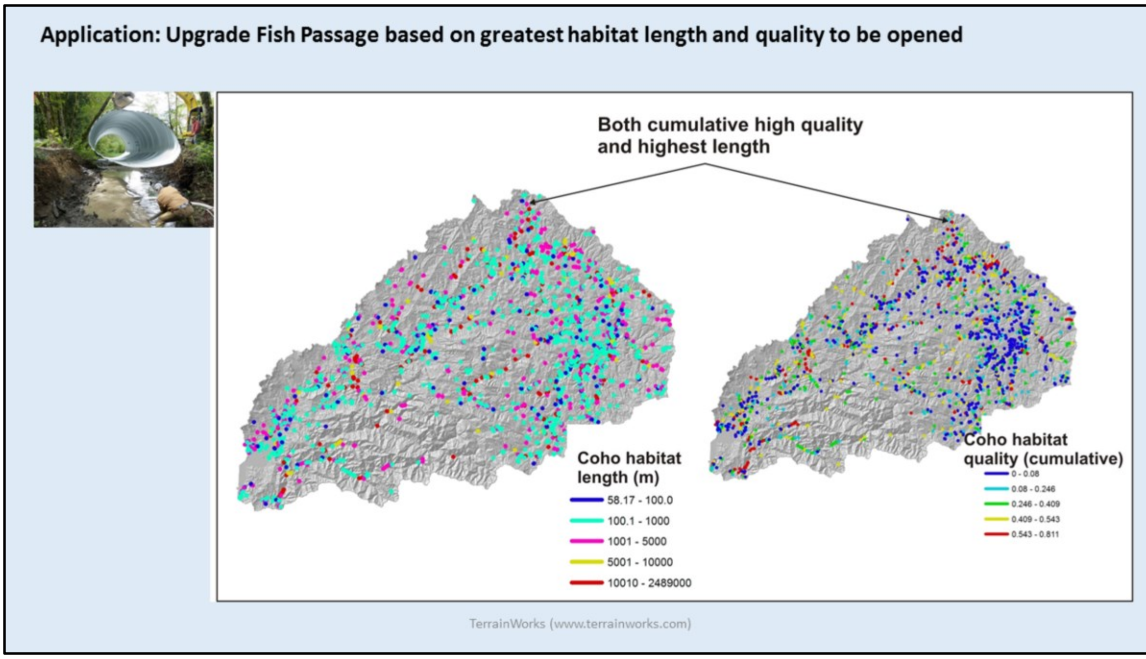
A similar analysis approach is used for roads in the Nehalem. Information on potential road related stressors can be considered individually or in combination, and compared to predicted habitat conditions, such as coho habitat quality (IP), as shown in this slide.



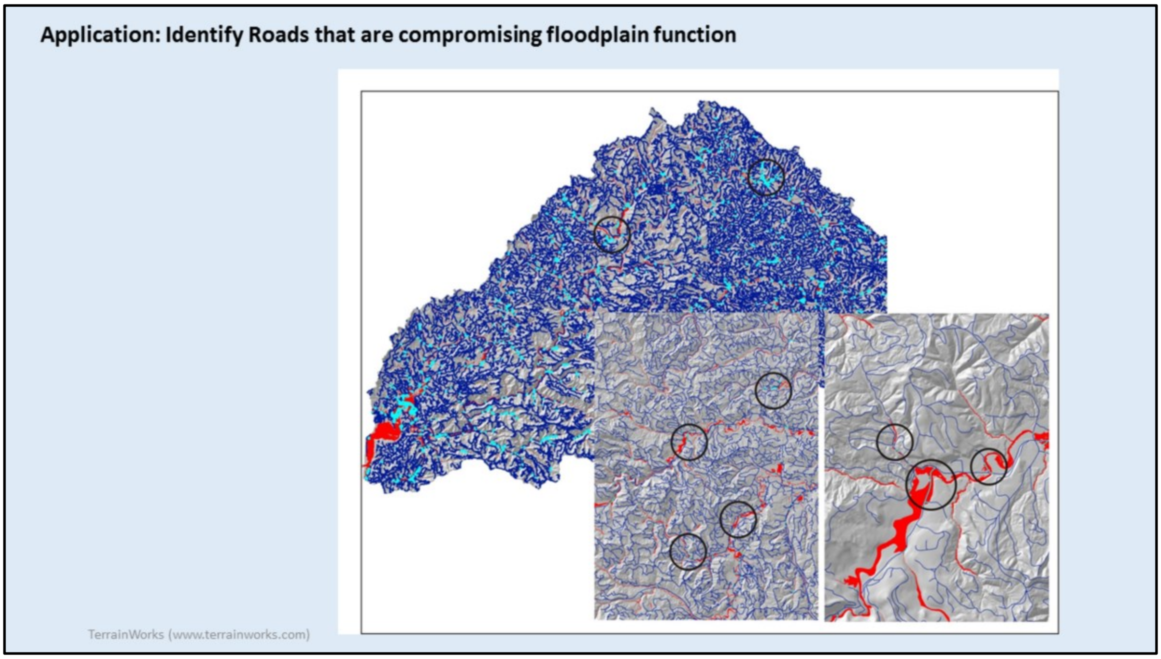
A similar restoration decision space can be used for road related issues. Cumulative distributions of road related information can be used to help identify and prioritize restoration activities.



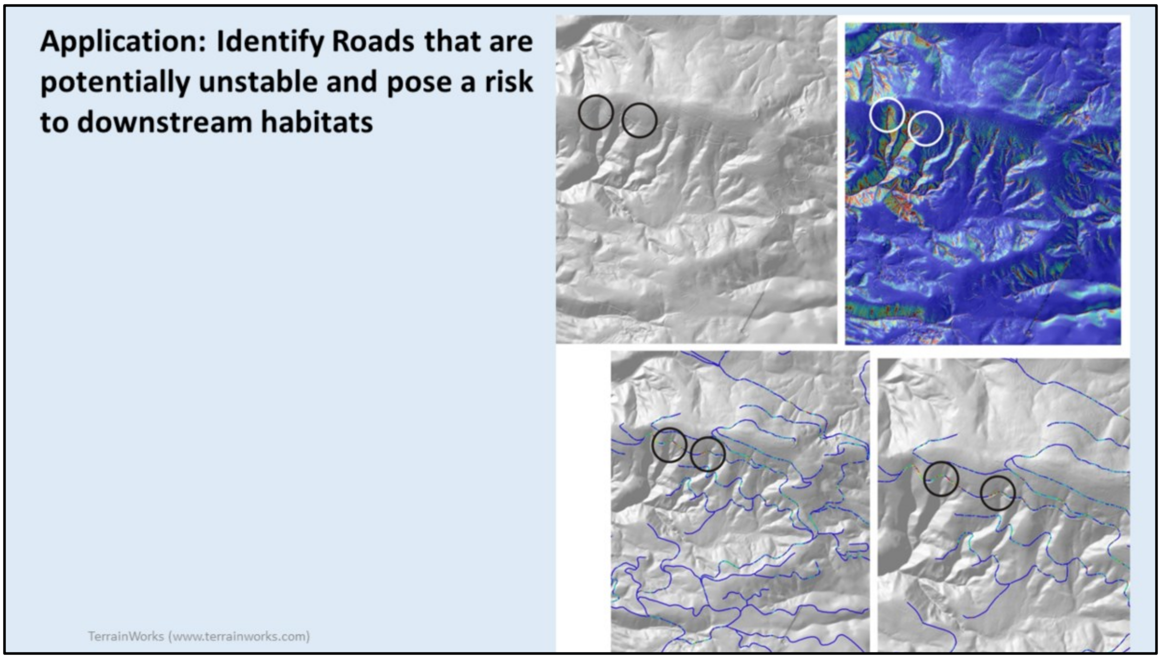
There is no shortage of roads in the Nehalem. Road density (length per area) is often considered a proxy for cumulative impacts. Road density is generally calculated at the scale of entire watersheds or subbasins (upper right); values in the Nehalem extend to about 4.3 km/km^2. In NetMap, road density is also calculated at the scale of individual 100 m channel segments via their associated small drainage wings. Calculated this way, road density extends up to 70 km/km^2. Road density could be considered during watershed scale restoration planning.



One type of road restoration planning involves reducing fish migration barriers by upgrading culverts, installation of bridges etc. In NetMap there is a tool for quickly calculating the cumulative habitat length and quality above all road-stream crossings. Such information could be used to help inform site selection for improving fish migration and movement.

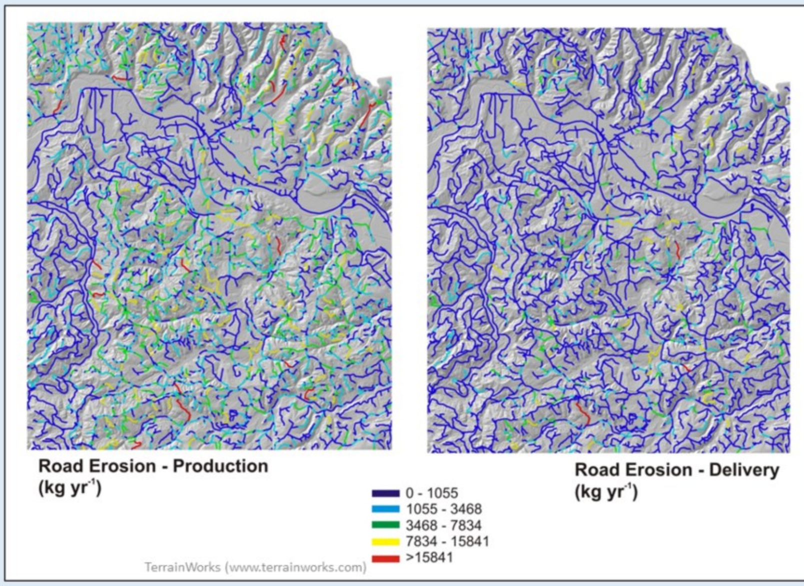


Another type of road restoration is removing roads from floodplains or redesigning them to lessen impacts. Once floodplains are mapped using NetMap tools (see earlier), a quick click of the mouse identifies all locations in the watersheds where roads are located in floodplains.

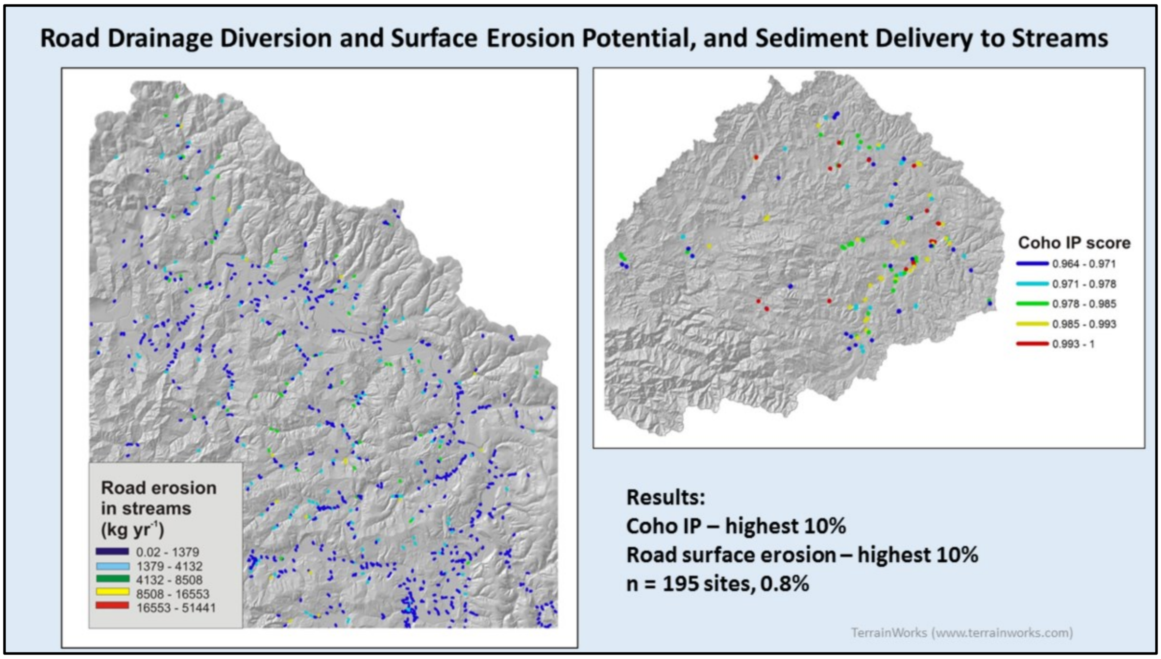


Roads are divided into pixel scale segments and then each of those are classified according to the predicted underlying hillslope stability, as shown in this slide. This information could be used to inform field programs to check on road conditions and to plan restoration to reduce road failure potential, including side-cast pullback and drainage diversions.

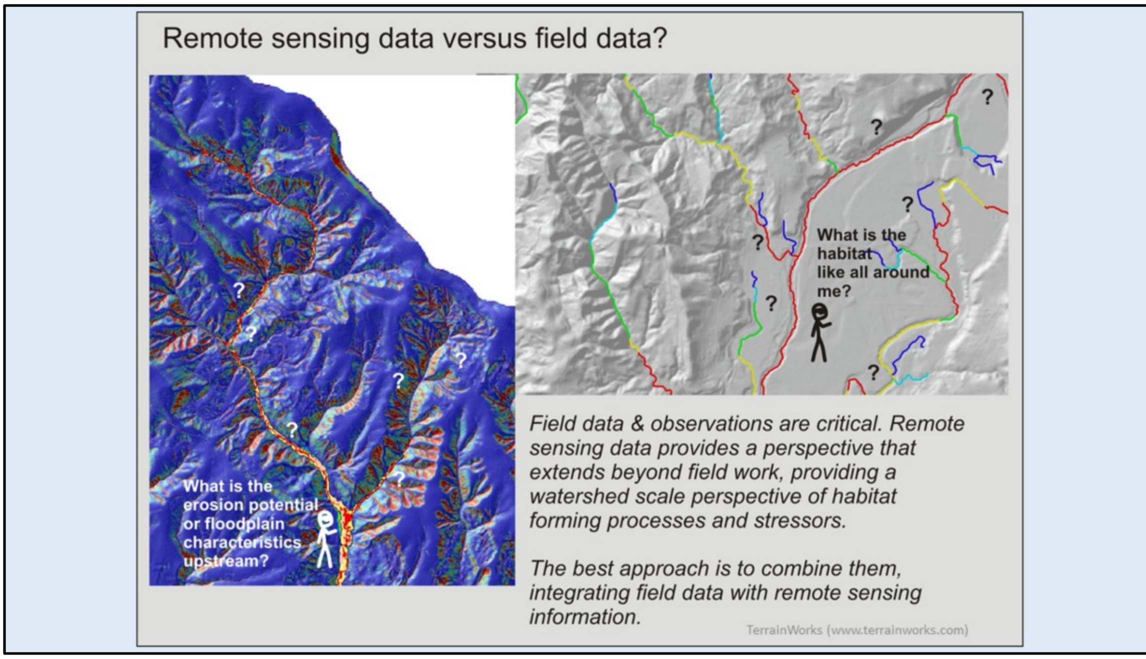
Application: Identify road segments with the greatest runoff and erosion potential and sediment delivery to streams (mapped to roads)



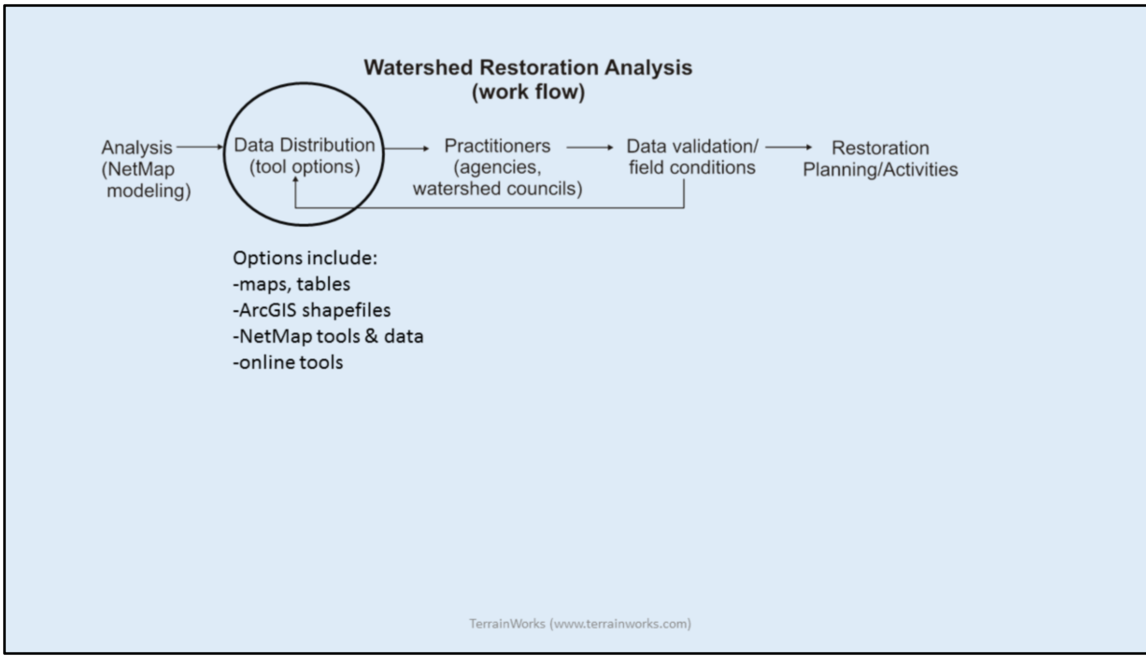
An important consideration with regards to road restoration is road drainage diversion, road sediment production and sediment delivery to streams. NetMap contains tools to predict road drainage (including using analyst supplied GPS road drain locations), road sediment productions (using WEPP and GRAIP-lite) and sediment delivery to streams. The results shown above are mapped to individual, hydrologically connected road segments.



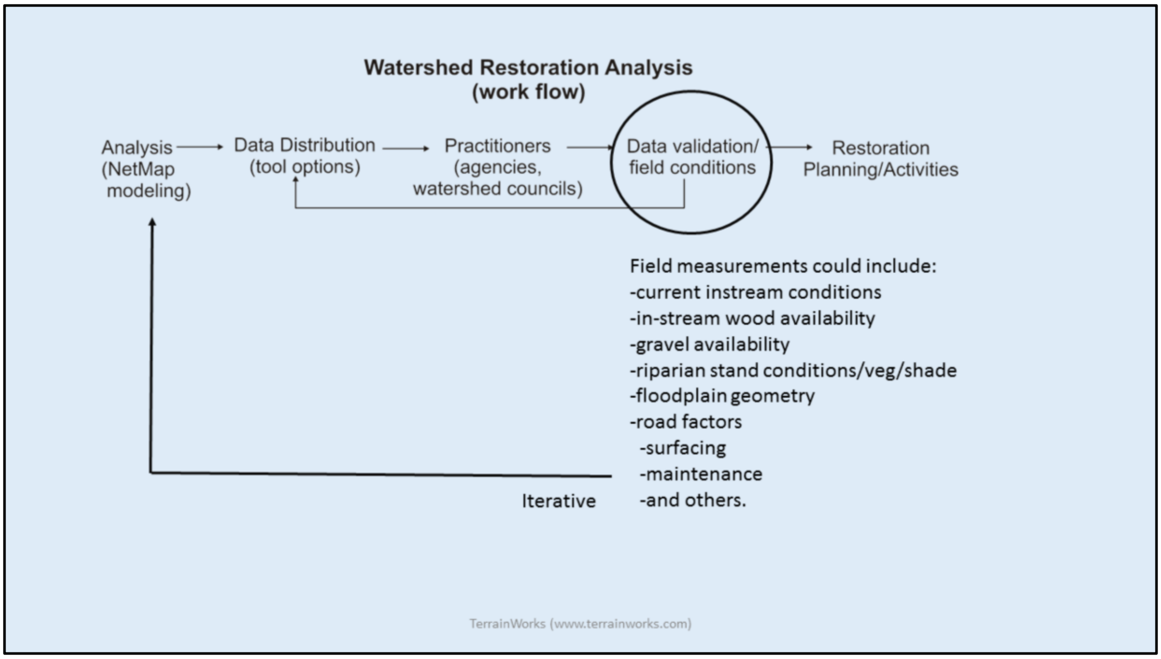
Predicted delivery of road erosion to streams is shown on the left panel and shows point sources of road surface erosion to stream channels; note the discontinuous nature of the road sediment point sources. This information can be overlaid onto coho habitat quality, yielding the panel figure on the upper right. This shows the locations where the highest 10% of coho habitat quality (IP) overlaps with the predicted highest 10% of road surface erosion. Restoration related to roads could target those locations, once field surveys have validated model predictions.



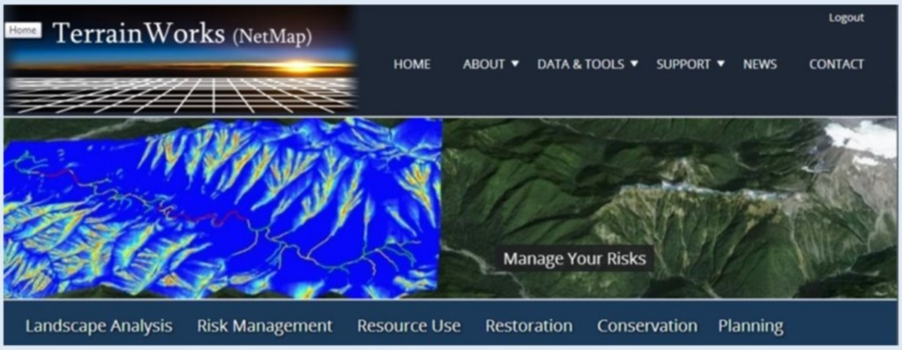
Field data on actual stream and road conditions are critical, and typically agencies and watershed councils have such information available. However, remote sensing analysis such as what is described in this PPT provides a much needed larger spatial perspective of conditions surrounding any particular field site. The best approach is to combine both types of data, integrating them together. All remote sensing information needs to be field verified as well.



There are various options for data distribution to users in the course of watershed restoration planning including maps, tables and plots such as what is included in this PPT, ArcGIS shapefiles, NetMap tools and virtual watersheds (to continue to update and create new analyses) and online tools, such as the TerrainViewer (http://www.terrainworks.com/terrain-viewer).



Validating model predictions in the field is critical. There are many types of field measurements that can be obtained, some of those are listed.



TerrainWorks creates customized virtual watershed datasets that work with NetMap tools including utilizing LiDAR where available. If a watershed or landscape only has partial LiDAR coverage, we merge LiDAR with 10 m digital elevation data to create a seamless DEM.

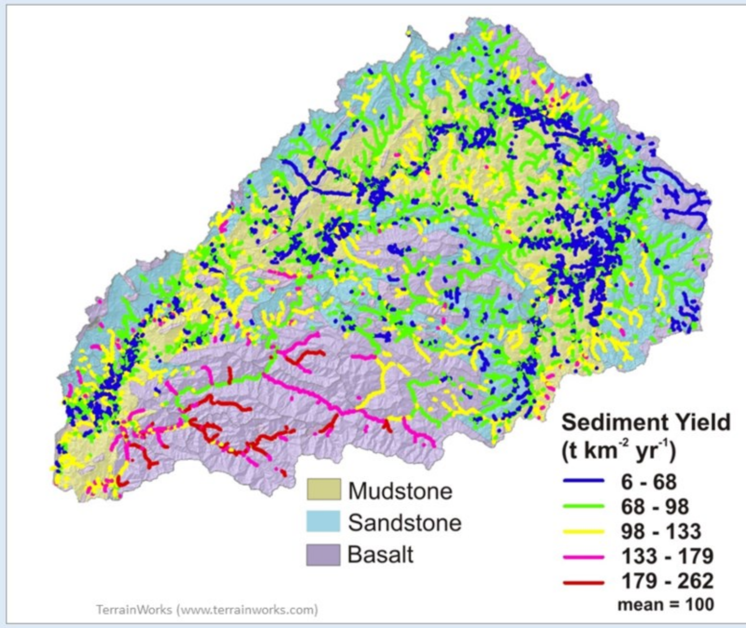
Learn more about NetMap virtual watersheds, watershed analysis tools, technical help and online tools at: www.terrainworks.com. Contact us with questions, we are here to help.

Addendums Follow for:
-Adding Gravel Supply
-Addressing Estuaries
-Mapping the Big Picture: TerrainViewer

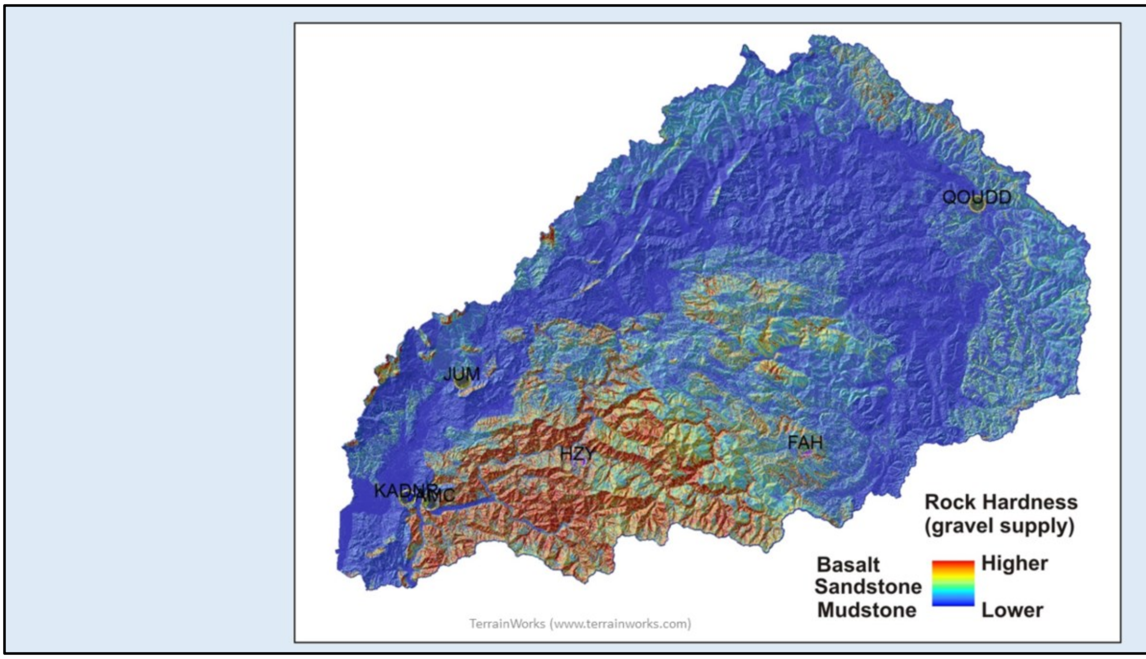
In-stream Structures Require Sediment to Function Properly (create pools)

Here are a few examples of in-stream structures designed to capture sediment to create pools but because of naturally low gravel sediment supply, the structures are not functioning as designed. Thus sediment supply in the form of gravels need to be considered when placing and designing in-stream structures.

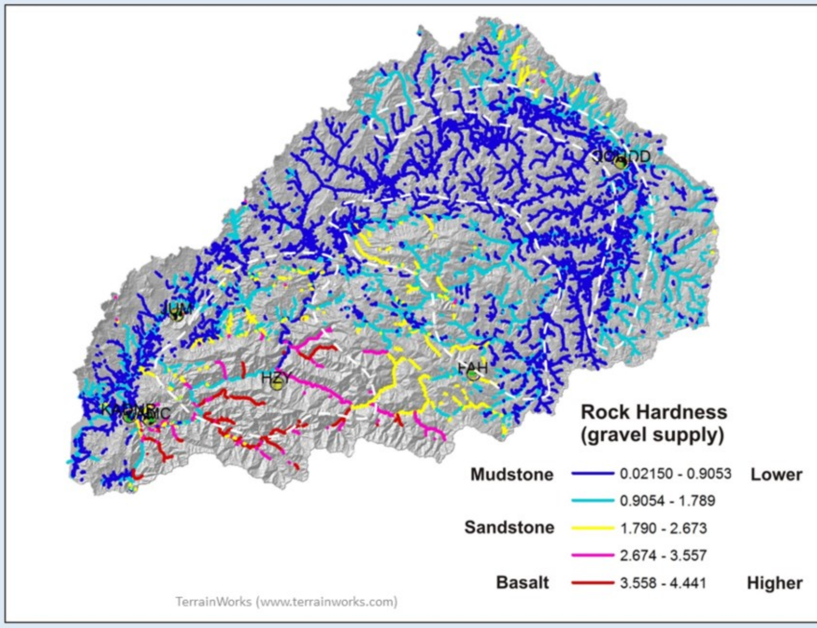
Addendum: Add Gravel Supply,
e.g., erosion driven by hillslope
gradient & convergence, plus consider rock hardness that is
related to ability to create gravels



NetMap converts topography, defined by hillside gradient and convergence into a measure of annual sediment yield, and as depicted in channels in this slide. The lower relief and less steep areas have lower predicted sediment supply, compared to steeper areas that have a higher predicted yield.

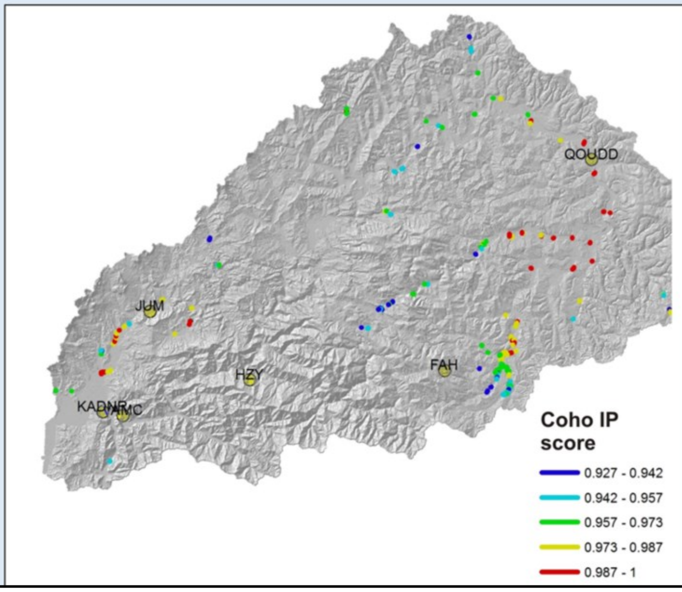


Rock types in the Nehalem watershed can be converted to indices of rock hardness, a proxy for gravel supply.



NetMap's erosion and sediment supply index (described above) is combined with the index of rock hardness to derive predictions of gravel supply potential, as shown here. The dark blue channel segments are predicted to have low gravel supply while the warmer colors are predicted to have a higher potential for gravel sediment supply.

Combine coho IP + in-stream wood recruitment + gravel supply

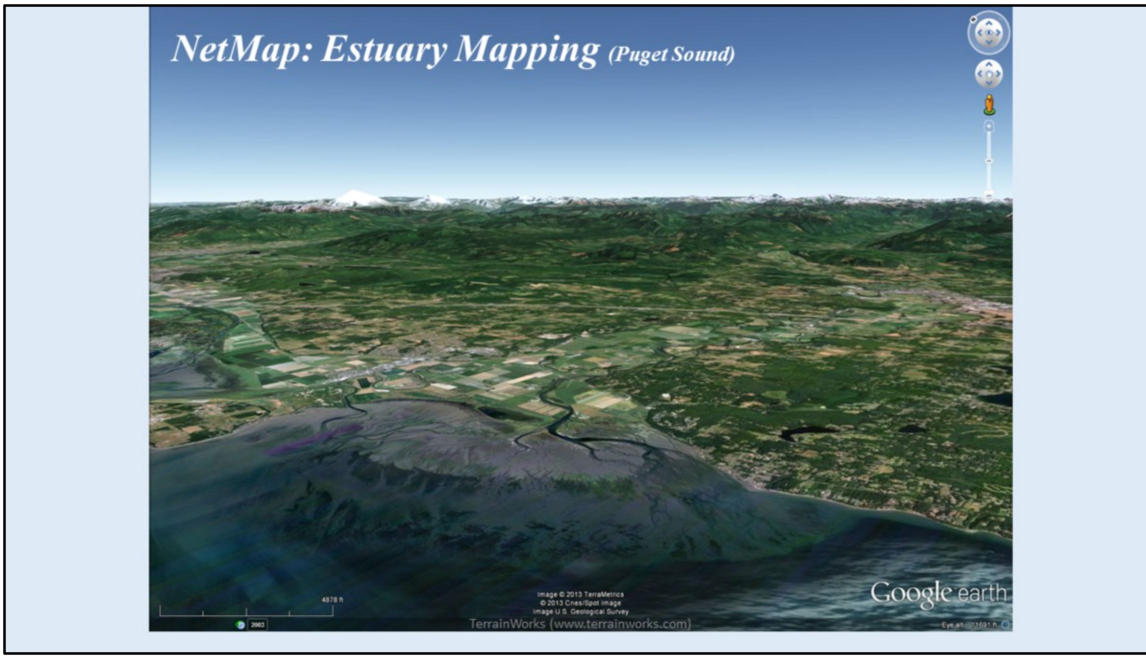


For example, locate area with the highest coho intrinsic potential (top 15%), the highest in-stream wood recruitment (top 15%) and the highest gravel supply (top 50%).

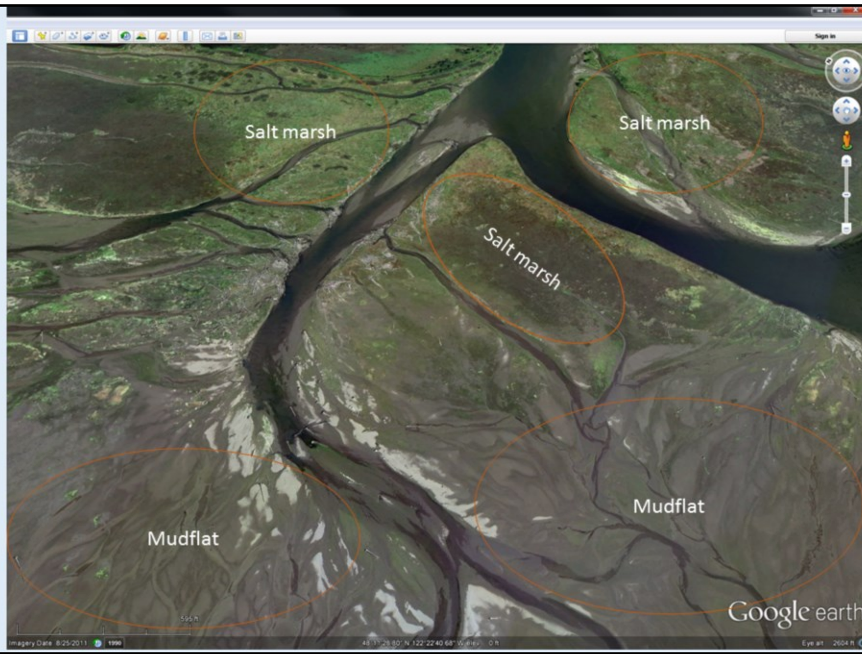
This yields 226 sites or 1% of the channel network

TerrainWorks (www.terrainworks.com)

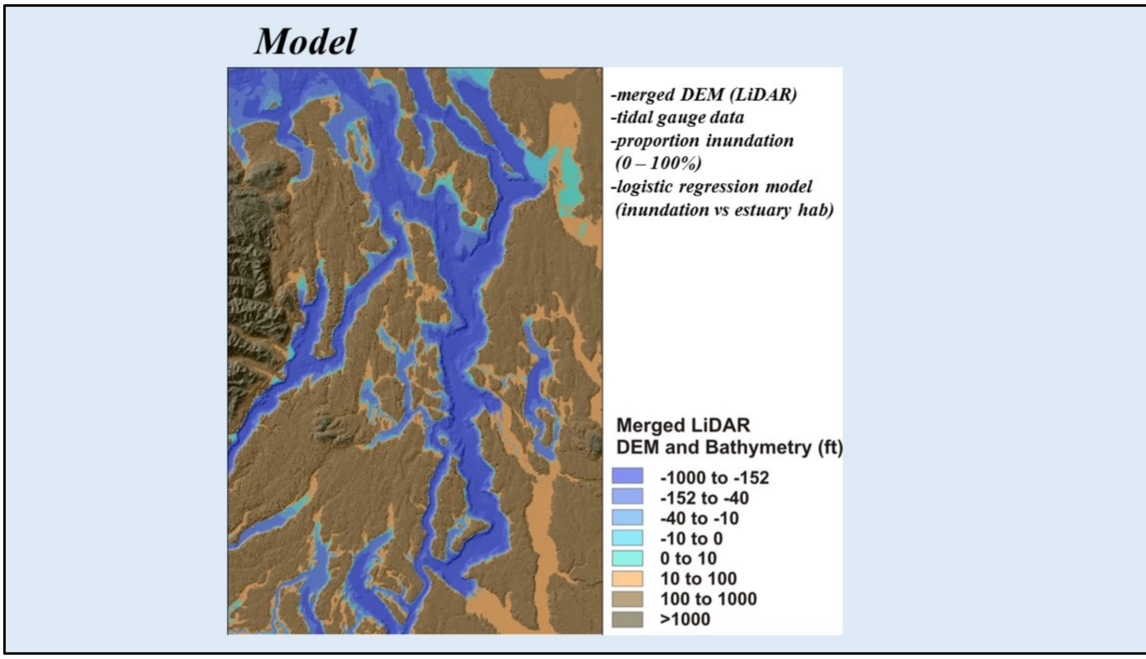
Predicted gravel supply is combined with coho habitat quality to search for overlaps where in-stream structures would have adequate sediment to create pools.



EPA funded the development of estuary mapping capabilities in NetMap in the Puget Sound. The tools are not part of NetMap's tool box but they can be applied by TerrainWorks in other areas, and they are particularly effective in coastal areas with LiDAR DEMs



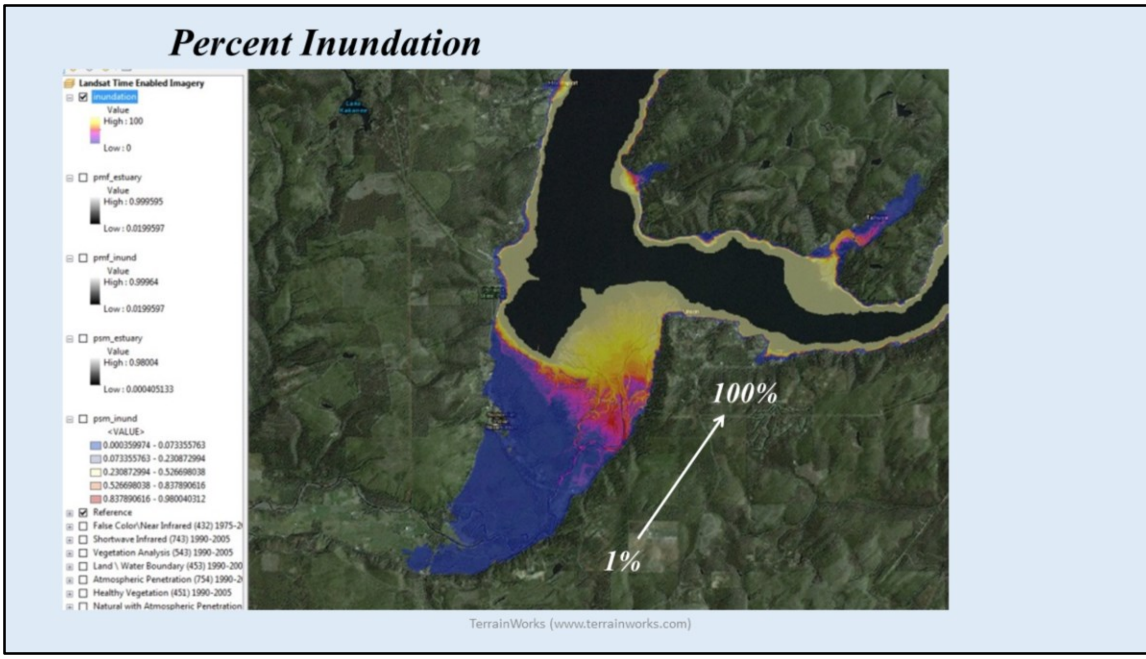
The estuary tool is designed to map estuary areas, including those that have been converted to non estuary areas due to historical land uses, including dikes and agriculture.



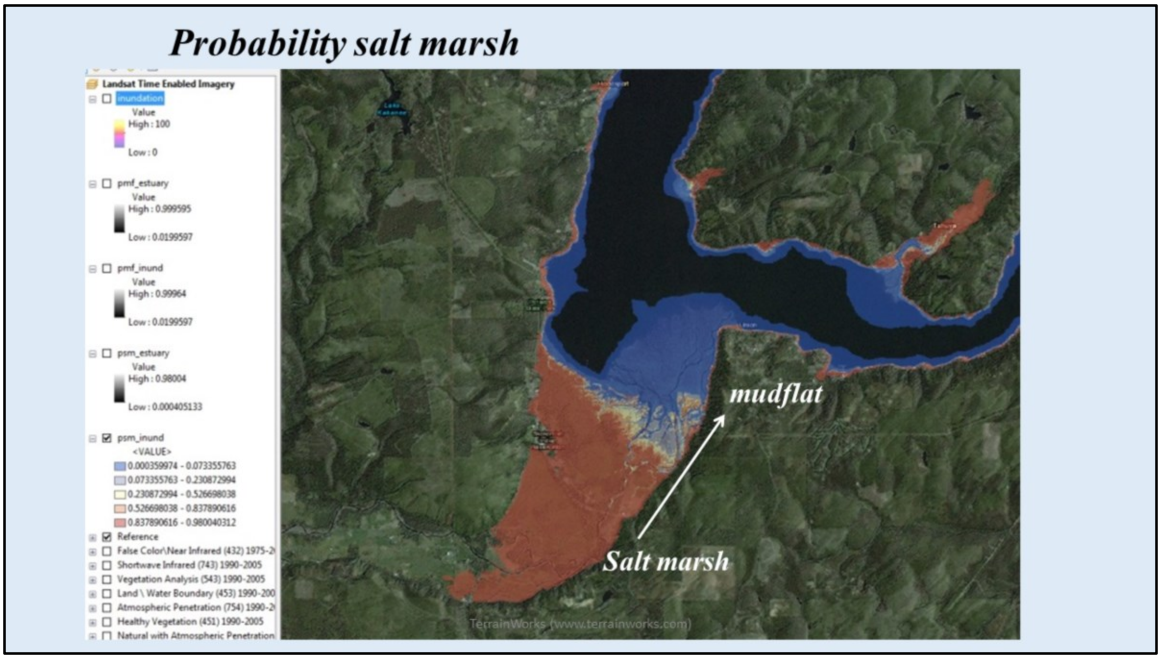
The estuary mapping model requires a DEM (LiDAR or some combination of LiDAR and 10 m) and tidal gauge data. The model calculates proportion of the year inundated with salt water (0 – 100%) and it then uses a logistic regression model to predict the distribution of salt marsh versus mud flat.

Results

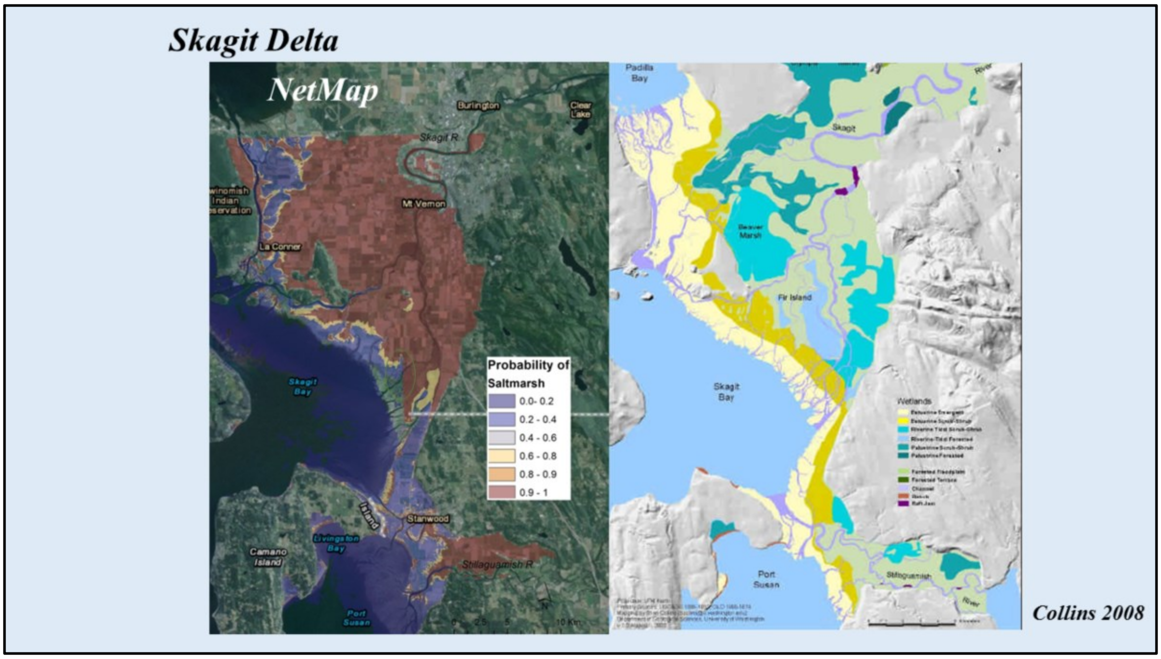
Skokomish River estuary



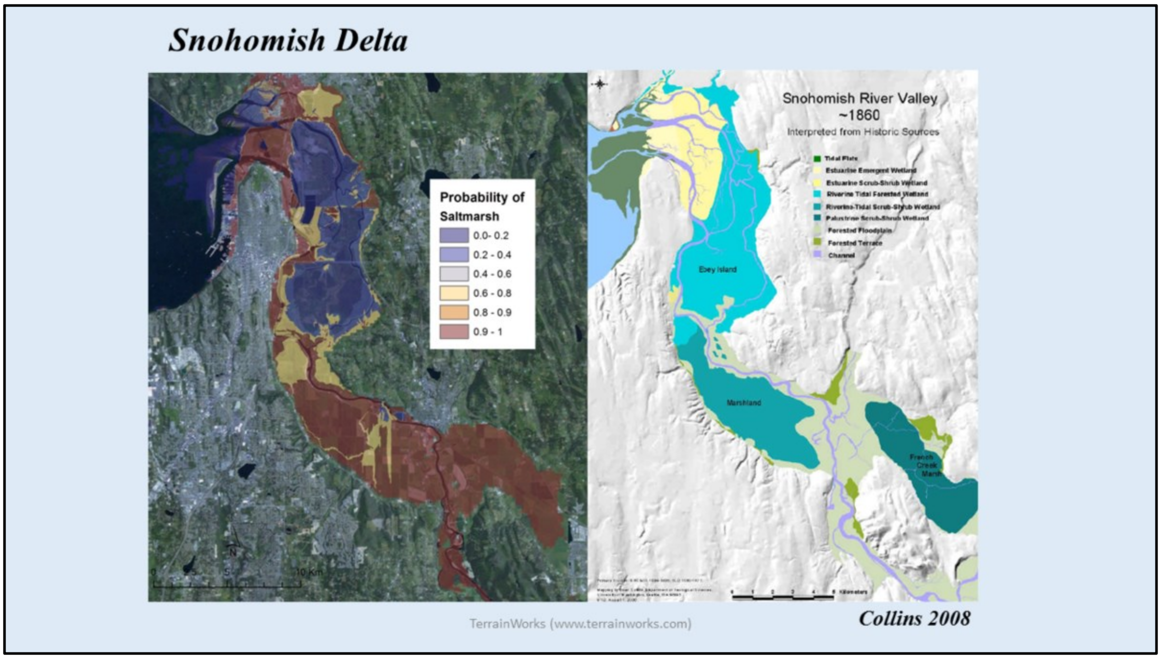
Here are some example results for a natural (non land use impacted) estuary in the Puget Sound, mapped as a proportion of time, during a year, inundated with salt water.



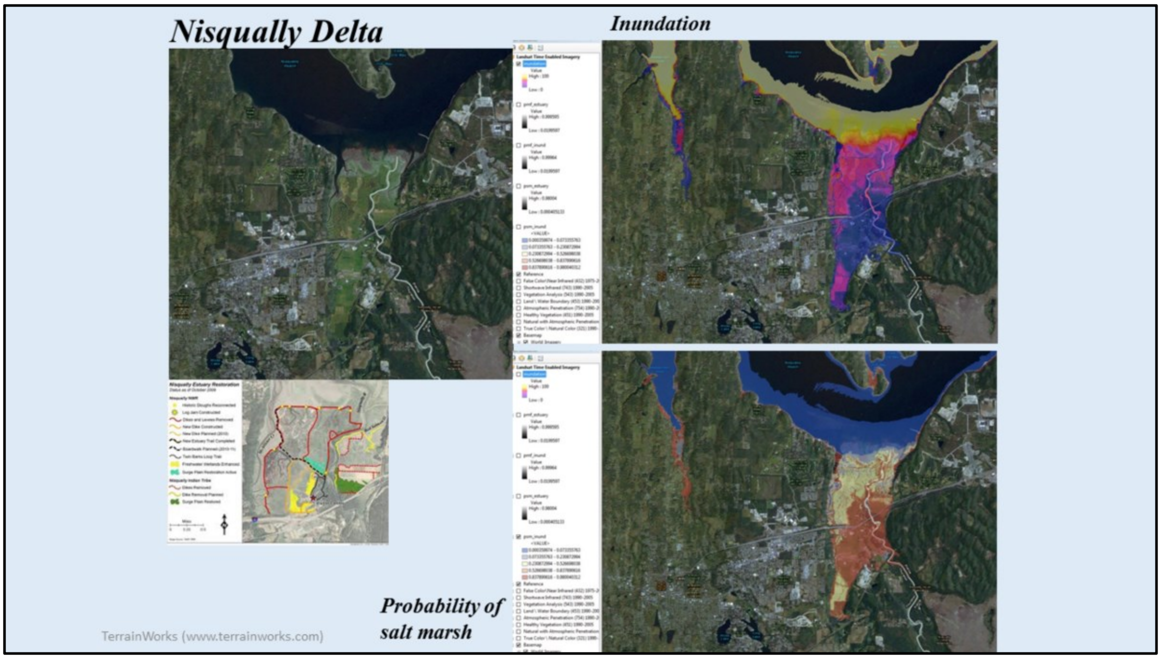
Next, using a logistic regression, the probability of salt marsh and mudflat is calculated.



NetMap's floodplain mapping tool can identify areas that have historically been estuary habitats (salt grass and mudflats) but that are now converted to non estuary lands. The panel on the right is a historical reconstruction of the Skagit delta estuary (Collins 2008) in northern Puget Sound. Model results closely match the historical reconstruction.

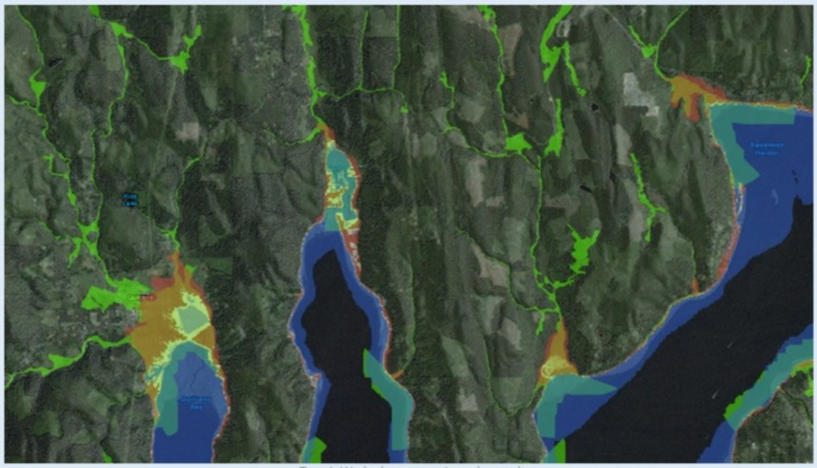


Another example for the Snohomish Delta in the Puget Sound.



Another example for the Nisqually Delta in the Puget Sound.

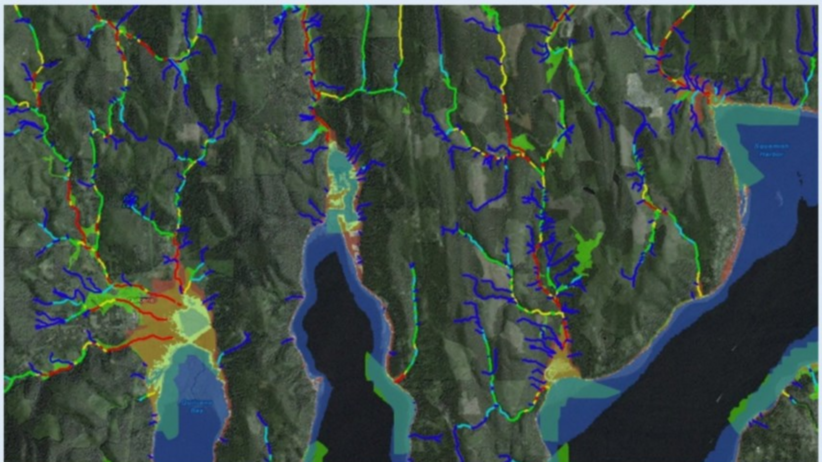
New classification schemes: estuary + floodplain



TerrainWorks (www.terrainworks.com)

Using NetMap’s floodplain and estuary mapping tools, new ecological classification systems can be developed.

New classification schemes: estuary + floodplain + fish hab



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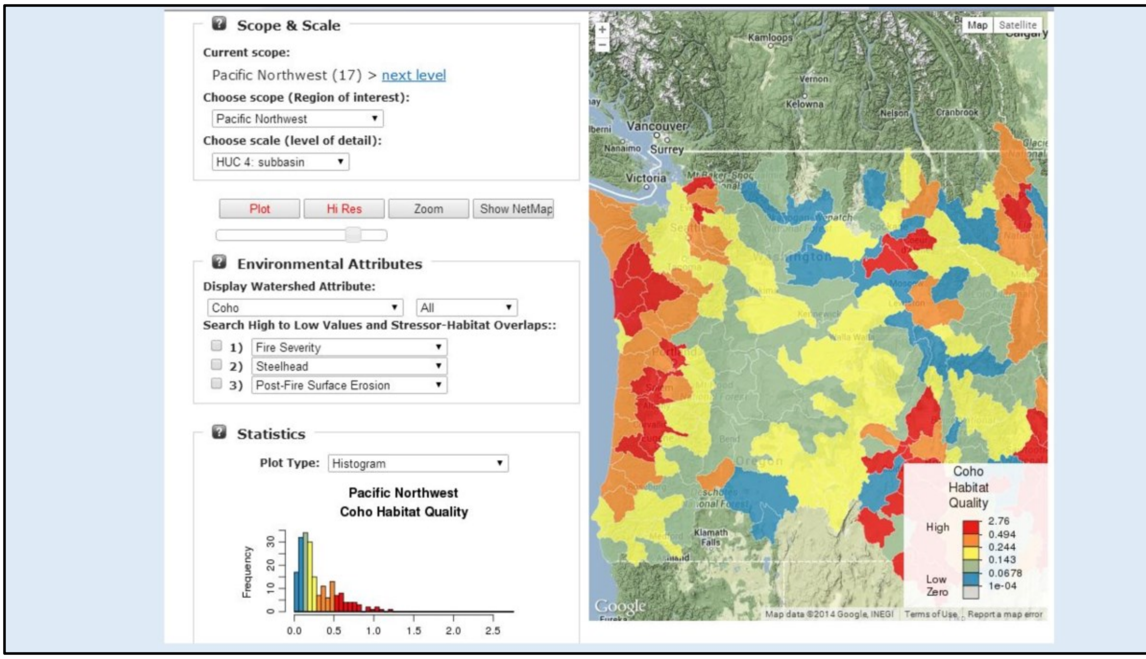
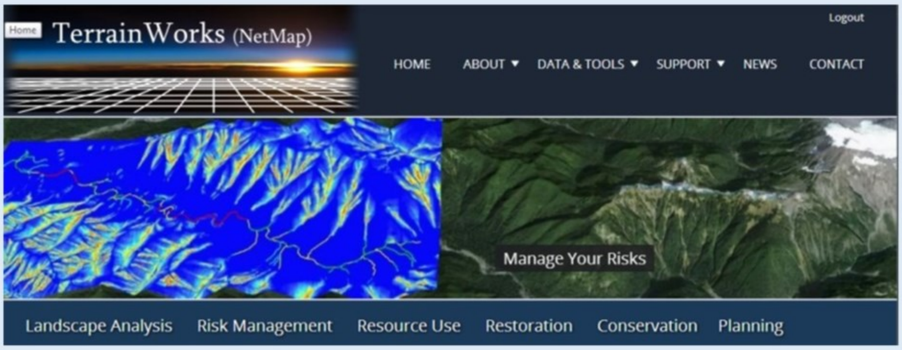


Put your watershed scale analysis into perspective at the landscape and regional scales using the TerrainViewer, at www.terrainworks.com; go to: http://www.terrainworks.com/terrain-viewer



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