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12/17/2012

Mr. Chandler Peter
US Army Corps of Engineers
Denver Regulatory Office
9307 South Wadsworth Blvd.
Littleton, CO 80123

Re: **NISP's impacts on riparian areas including wetlands along the Cache la Poudre River**

Dear Mr. Peter,

The National Environmental Policy Act requires, when applicable, a full accounting of potential wetland community impacts associated with significant proposed actions.

As you will find in the attached report, we used a Geographic Information System to estimate the acreage of wetlands and other riparian community components along the Cache la Poudre River corridor that would most likely be adversely impacted by the proposed Northern Integrated Supply Project's reduction in peak river flows.

If NISP were built, it would dramatically reduce peak flows in the spring and early summer. We found that the NISP, because of its significant alteration of the river's hydrologic regime, will disturb between 1420 and 2170 acres of critical riparian areas, with our best estimate being 1700 acres. Of this, over 700 acres are wetlands.

Dahl (2011) has stated, "[N]ational wetland losses have outdistanced gains. The cumulative effects of losses in the freshwater system have had consequences for hydrologic and ecosystem connectivity. In certain regions, profound reductions in wetland extent have resulted in habitat loss, fragmentation, and limited opportunities for reestablishment and watershed rehabilitation."

We cannot afford to reduce peak flows along the Poudre River in the face of an already declining riparian wetland resource and the critical social, economic and environmental values they provide. And, we cannot afford to do this in the face of wetland and riparian declines throughout the western U.S. and even worldwide.

Adversely affecting these rare riparian resources by degrading and fragmenting them further flies in the face of the very principles of responsible natural resource management. Specifically, borrowing from Dale et al. (2000), any serious analysis must (1) examine the impacts of local decisions in a regional context; (2) plan for long-term change; (3) preserve rare landscape elements and associated species; (4) avoid land uses that deplete natural resources over a broad area; and (5) retain large contiguous or connected areas that contain critical habitats; (6) minimize the introduction and spread of non-native species; (7) avoid or compensate for effects of development on ecological processes; and (8) implement land use and land management practices that are compatible with the natural potential on the area. We would go so far as to say that degrading the Poudre River's riparian zone countermands the Corp's own nationwide guidelines (Fischer and Fischenich, 2000).

In addition to going against nationwide guidelines, we also must carefully examine the screening criteria used to bound the various NISP alternatives as described in the DEIS. The following is an excerpt from section 2.1.22 of the NISP DEIS ("Environmental Screening Criteria"), page 2-5, regarding wetlands:

> Wetlands are special aquatic sites as defined in 40 CFR 230.41 and are part of the aquatic ecosystem. Elements that passed this screen did not cause permanent, direct loss to 60 acres or more of wetlands. Wetland areas were estimated using National Wetland Inventory maps, the Phase II report (MWH 2004), and/or geographic information system (GIS) tools, as discussed in the Alternatives Evaluation Report (HDR 2007a).

Our study utilized similar methods described in the NISP screening analysis, including an up-to-date wetland inventory for the Cache La Poudre River watershed adopted by the National Wetlands Inventory, and extensive GIS analysis. It shows that the proposed NISP would adversely affect over 700 acres of wetlands in the Cache la Poudre basin, not including additional wetlands loss from the South Platte basin downstream of the confluence with the Poudre River. This loss is an order of magnitude above the 60 acre wetlands loss criterion adopted in the DEIS for the Alternative Screening process. Thus, we believe that NISP violates the screening criterion and therefore is not a viable alternative to meet the water needs of the NISP proponents.

In conclusion, our analysis indicates that impacts to nationally important downstream wetlands and riparian areas will be very extensive. Therefore, Save The Poudre requests that the upcoming Supplemental DEIS thoroughly evaluate the NISP proposal specifically to better quantify the extent and nature of the impacts on riparian communities, especially wetlands since some (perhaps many) will be legally protected. This should be done against the backdrop of reasonably foreseeable hydrologic changes to the Poudre River through Fort Collins to the South Platte River and further downstream. In addition, this should be done against the backdrop of the screening criteria in the DEIS, which screened out any alternative that would adversely impact more than 60 acres of wetlands – stated differently, NISP should be screened out because it would adversely impact at least 700 acres of wetlands. Failure to consider these impacts, we believe, would fail to comply with NEPA and the Clean Water Act.

As with all of our communications during this pre-Supplemental period, you can expect that we will resubmit during the next public comment period. Nonetheless, we would appreciate confirmation of this letter and attachment.

Sincerely,

Mark Easter and John Bartholow

cc: Jim Martin, Director Region 8, U.S. Environmental Protection Agency

Attachment: Estimating the Extent of NISP's Impacts On Riparian Areas and Wetlands Along the Cache la Poudre River

References

Dahl, T.E. 2011. Status and Trends of Wetlands in the Conterminous United States 2004 to 2009. U.S. Fish and Wildlife Service, Fisheries and Habitat Conservation, Washington, D.C. Report to Congress. 107 pp. Available on the Internet at http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-in-the-Conterminous-United-States-2004-to-2009.pdf

Dale, V., S. Brown, R. Haeuber, N. Hobbs, N. Huntly, R. Naiman, W. Riesbsame, M. Turner, and T. Valone. 2000. Ecological Society of America report: Ecological principles and guidelines for managing the use of land. Ecological Applications 10:639-670.

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Estimating the Extent of NISP's Impacts On Riparian Areas and Wetlands Along the Cache la Poudre River

Save The Poudre: Poudre Waterkeeper
12/17/2012

Summary of Findings

We used a Geographic Information System to estimate the acreage of wetlands and other riparian community components along the Cache la Poudre River corridor that would most likely be impacted by the proposed Northern Integrated Supply Project's reduction in peak river flows.

To accomplish this, we developed a simple, four-step model that intersected previously digitized wetland boundaries with concentric bands representing zones of increasing elevation above the river channel. Combining these intersected layers with information regarding the estimated post-project change in peak river stage, the characteristics of bank storage and soils, and the hydrologic needs of wetland communities allowed us to tabulate the acreage of riparian areas, including wetlands, that would be adversely affected along the plains portion of the Poudre River.

We found that the NISP will adversely affect between 1420 and 2170 acres of wetlands and other riparian areas. Our best estimate is 1700 acres, of which over 700 acres are wetlands.

Introduction

Value of and Threat to Western Riparian Wetlands

Water is an important limiting resource for all plants: fitness, vulnerability to pathogens and herbivory, richness, productivity, biomass, competitive ability, population structure and community composition are supported by and respond directly to water availability (Merritt et al., 2010). In the Southwest, riparian areas disproportionally support a majority of the region's animal and plant species, and are valued for recreation, watershed protection and water quality (discussed by Horton et al., 2001; Nilsson and Svedmark, 2002). Yet today, less than 20% of the riparian habitat present 100 years ago remains (Swift, 1984, as cited by Horton et al., 2001) and the structure and function of much of what remains has been compromised and is still being lost (Dahl and Allord, 1997). Of the 295 species of birds, 123 mammals, 47 reptiles, and 18 amphibians that inhabit Colorado at some time during the year, 125 (26%) can be classified as wetland-dependent species. Within this category of “wetland wildlife,” 98 species (78%) are migratory birds, 18 (14%) are amphibians, 6 (5%) are reptiles, and 3 (1%) are mammals (CDPW, 2011). The Colorado Natural Heritage Program has classified wetlands in the northern Front Range area as being in the severe stress category, in part because 34% of the species mentioned above (n=42; 29 migratory birds, 11 amphibians, 1 reptile, and 1 mammal) have been categorized as “rare and imperiled,” and in part because cumulative impacts from pollution, development, draining, other changes in hydrology have crippled most of our natural wetlands and severely altered the ability of remaining wetlands to support many of these imperiled species (CDPW, 2011).

In this report, we treat wetlands and other riparian areas as a single community that has evolved throughout the western United States adjacent to streams – like the Poudre River – that empty from higher elevations and recharge alluvial aquifers beneath the plains. It is the entire community mosaic that adds value to our landscape (Crifasi, 2005), not any single vegetative type. This community forms along a moisture gradient with the moist wetlands at one end and the more mesic cottonwood/willow complex at the other. This riparian community provides a wealth of ecosystem services and functions, including (1) stabilizing erosion by supplying high density, fibrous root masses; (2) filtering sediments, nutrients, pesticides, and animal wastes (like ecosystem kidneys) – non-point contaminants responsible for more than half of the pollution in our nation’s waters; (3) influencing microclimate (light and temperature); (4) promoting groundwater recharge; (5) adding multi-story terrestrial habitat structure and large woody debris that contributes to the maintenance of a more variable and complex range of aquatic habitats, i.e., reduced velocity; (6) supporting wildlife and livestock; (7) supplying food for stream biota; (8) stabilizing the equilibrium between channel aggradation and degradation; (9) accreting organic matter that adds to the soils’ ability to hold water; and (10) contributing and enhancing recreation (USDA NRCS and New Mexico Plant Materials Center, 2000; Obedzinski et al., 2001; Nilsson and Svedmark, 2002).

It is the exact nature of the moisture gradient that shapes the character and dynamics of the riparian community from location to location. Simply stated, if there is no water, there will be no moisture gradient. Two mechanisms in particular govern the moisture gradient adjacent to a stream: periodic inundation of and capillary transmission through the soil to the adjacent riparian community. Indeed, the very definition of *riparian* reflects the decisive importance of streamflow in elevating near-stream water tables and providing overbank flooding events that irrigate, clean and fertilize areas and further recharge the water table (Nilsson and Berggren, 2000; Rood and Mahoney, 1990). Surface water in alluvial valleys is hydraulically connected to shallow groundwater in the floodplain aquifer and the water table fluctuates with changes in river stage and volume, resulting in varying amounts of water available in the rooting zone (Stromberg and Patten, 1996).

Because of the intimate streamflow connection, the general composition, structure and abundance of these riparian communities are now suffering from widespread changes to the local hydrology that impacts the shallow alluvial groundwater and disturbance events (Rood et al., 2003; Merritt et al., 2010). Such impacts have been unambiguously demonstrated as dependent on streamflow through multiple lines of evidence, most clearly by focusing on the dominant community member, the plains cottonwood: (1) cottonwoods are restricted to streamside bands up to about 3-4 m above base river stage; (2) damming and dewatering have provided experimental verification of direct tree mortality; (3) carefully managed supplemental flows have reversed losses to, or in some cases re-initiated, cottonwood growth; (4) tree growth in these ecosystems is highly correlated with annual streamflow; and (5) isotopic analysis of xylem water has identified the source of any given plant's water (Stromberg and Patten, 1996; Rood et al., 2003).

When alluvial groundwater has been depleted as a result of either acute or chronic river dewatering, shallowly rooted riparian cottonwoods exhibit classic drought responses, including unsightly branch sacrifice and crown die-back, ultimately leading to premature tree mortality (Rood et al., 2003; Scott et al., 1999; Scott et al., 2000) and lack of cottonwood community sustainability (Nilsson and Berggren, 2000). The effect of groundwater level declines, moreover, is not linear. Instead, vegetative condition declines rapidly after the depth to groundwater exceeds a distinct threshold (Horton et al., 2001). Further, the seedling stage may be the most vulnerable for most wetland species, the stage that is particularly affected by both infrequent high flow events (positively) and more frequent drought-like periods (negatively) (Rood and Mahoney, 1990; Merritt et al., 2010). If seedling replenishment is not frequent, the gallery cottonwood system cannot be maintained (Rood and Mahoney, 1990).

Collapse of multiple, locally important riparian communities have been well documented along rivers throughout the water-scarce western U.S. (Rood et al., 2003) and other similar areas (Nilsson and Berggren, 2000). When the overstory dies without a well established understory, then drought-tolerant, invasive/exotic species colonize and reduce the potential for future native woody vegetation. Thus, such collapses usually are followed by the gradual invasion of exotic, shade tolerant and vegetatively-spreading species facilitated by the river corridor's dispersal pathway (Nilsson and Berggren, 2000; Obedzinski et al., 2001). These same changes have been documented by Strange et al. (1999) for the whole South Platte basin that has been adversely affected by alterations to the timing, magnitude, and duration of peak flows and elevated summer base flows.

Such changes in community composition may themselves be non-linear or respond to threshold conditions or feedbacks. For example, elimination of high water events can result in less flushing of streamside soils, favoring buildup of salts. These salts in turn alter the competitive advantage of salt-tolerant exotics such as *Tamarix spp.*, which in turn accelerate the depletion of groundwater and contribute even more salts through their own leaf drop – a vicious cycle that further strengthens the collapse of species like cottonwood and willow and reduces the probability of restoring native plant communities (Busch and Smith, 1995).

Further, impacts to riparian areas are often cumulative, i.e., altered hydrology can and does interact with abiotic factors (e.g., periodic climactic stresses, direct habitat conversion along with armoring of banks and related channel confinement) and other biotic factors (e.g., invasives) to substantially impair or degrade the structure and function of riparian wetland communities.

Finally, a healthy, functioning riparian zone in turn supports a healthy aquatic system. Water stored in the riparian zone's sediments (often to the point of actually reducing peak flood flows) is released gradually from bank storage sustaining both the vegetation and the river's base flows (Hantush et al., 2002). Thus, though our focus in this paper is the riparian zone and associated wetlands, each community sustains the other; harm to one is in effect harm to both.

The Cache la Poudre Corridor Study Area

The City of Fort Collins Natural Areas and the State of Colorado Wildlife Areas along the Cache la Poudre River (Poudre River) are home for an array of animals, plants, fishes, insects and aquatic biota which delight regional residents and offer a respite from urban life. Our parks, Natural Areas and trail systems allow citizens ample opportunities to enjoy a wide variety of activities along the whole length of the Poudre as it journeys through our region. Fishing, boating, tubing, wildlife viewing and bicycling are just a few of the many recreation activities that citizens enjoy along this river. These activities have consistently proven to be of great importance to citizens and are ranked highly in terms of quality of life. For example, the view of the Poudre River was the number one desired "community character" image in a 1995 Visual Preference Survey (City of Fort Collins, 1995). Similarly, in a pubic survey commissioned by Great Outdoors Colorado (GOCO), respondents were asked to react to the statement "Wetlands are very important and should be protected by government". Fifty-five percent strongly agreed with the statement, and 28% somewhat agreed. Therefore, 83% of the public desires some form of wetland protection (CDPW, 2011).

Today's riparian communities are beneficial over and above their natural functions outlined above. For example, Fort Collins citizens have spent almost $10 million building a bike path and tens of millions more protecting open space along the Poudre River's riparian zone, both of which help promote the recreational and tourism economy for fly fishing, swimming and tubing, bird and nature-watching, biking and hiking – and just relaxing. According to a Fort Collins Natural Areas Program study, more than 100,000 user-days were logged on the Poudre River trail in 2007. Other cities have estimated the economic benefits garnered by maintaining a healthy, vibrant river community. For example, property values in urban areas with restored streams can increase $4,500 to $19,000 from actions like stabilizing stream banks and putting in educational trails (Streiner and Loomis, 1996). Some economists (e.g., Colby and Wishart, 2002) find that urban and suburban property values, and therefore also property tax revenues, are increased by millions of dollars simply through proximity to riparian areas in semi-arid regions like ours.

The Poudre River's riparian area is not immune to the same threats that other western rivers face. As it emerged from the mountains, the Poudre once formed a wide floodplain with an extensive gallery forest dominated by plains and narrowleaf cottonwood (*Populus deltoides* and *P. angustifolia*), sandbar willow (*Salix exigua*), and various understory herbaceous species. But aggregate mining within the floodplain, conversion of wetlands to agricultural and residential uses, the growth of urban centers, numerous water diversions, and creation of water storage reservoirs have all changed the structural composition of the landscape (Wohl, 2001, excerpted from Carlson and Lemly, 2011). Though there is some anecdotal evidence that the Poudre's cottonwood riparian community may have expanded its area once water development began along its channel in the 1860s, objective, quantitative information since 1937 points toward over-representation of senescent cottonwoods and thus a declining, non-sustaining riparian forest (Ayres and Associates, 2008; City of Fort Collins, 2008) and extirpation of associated (and rare) riparian plants (Fertig, 2000). Exotic species have moved in and species with limited abundance have increased; examples include crack willow, Russian olive and tamarisk.

Cottonwood and other trees in a mature riparian area will exhibit cyclical branch dieback from periodic droughts and age-related mortality. We cannot say whether the specific tree illustrated in Figure 1 – and the many others like it – is a result of dewatering or simply typical of the mature character of Poudre River bosque areas. Away-from-river dieback in general, however, is a symptom of a far less dynamic river than once flowed through this valley.

Figure 1. Example of a cottonwood tree immediately adjacent (laterally within 20-30 feet) to the Poudre River exhibiting away-from-river branch dieback that may be expected from water stress. The plains cottonwood is along the well-used (and almost completed) Fort Collins-to-Greeley bike trail in Colorado's Frank State Wildlife Area. Photo taken in June, 2012.

How Would NISP Affect the Poudre's Riparian Wetlands and Forests?

Trees and herbs that establish their root systems under a highly variable flow and groundwater regime may develop more vertically extensive root systems than those established under relatively stable surface and groundwater environments. This may predispose plants established under less variable groundwater regimes to greater moisture stress during channel dewatering, groundwater pumping or prolonged drought than plants established under more variable groundwater regimes (Merritt et al., 2010).

The Poudre River, though considerably affected by numerous water diversions, retains its connection with its floodplain along much of its course to the South Platte (Browne, 2009). The evolution of the river towards one with flatlined flows, especially smaller peak flows (Bartholow, 2011), makes current wetland communities much more vulnerable to the effects of dewatering. This vulnerability is perhaps especially true in side channels and backwaters that are no longer hydraulically connected to the river, but we suspect that wetlands and riparian areas all along the river would be harmed by further reductions in peak flows. (That said, we acknowledge that an undetermined portion of the wetland community may depend, in part, on alluvial and surficial return flows from irrigated agriculture and similar surface-use activities.)

The Northern Integrated Supply Project (NISP) draft Environmental Impact Statement (DEIS) shows that project would primarily divert peak river flows and, in effect, make almost every year's peak flow hydrograph resemble a dry year on the river (Table 1). Based on this, we sought to answer the question, how much of the wetland community along the river would likely be impacted given post-NISP hydrology? To answer this question, we created a GIS model.

Table 1. Average monthly streamflow (cfs) and percent difference at the Lincoln Avenue stream gage for the District's proposed action. Taken from Table 4-2 of the NISP DEIS.

Type of Flow and Representative Year	May	June	July
Baseline			
Wet	280.83	908.44	252.65
Average	188.60	529.40	174.50
Dry	131.12	215.44	66.41
Projected Flows			
Wet	163.50	368.90	172.27
Average	54.13	245.47	93.43
Dry	43.79	116.69	23.20
Change in Flow			
Wet	-117.33	-539.54	-80.38
Average	-134.47	-283.93	-81.07
Dry	-87.33	-98.75	-43.21
Percent Difference			
Wet	-41.8%	-59.4%	-31.8%
Average	-71.3%	-53.6%	-46.5%
Dry	-66.6%	-45.8%	-65.1%

Landform elevations relative to the river create the important physical gradients that determine frequency and duration of flooding, exposure to shear forces, deposition and scour, the characteristics of the deposited sediment and their water-holding capacity, and depth to the water table (Merritt et al., 2010). The Northern Integrated Supply Project DEIS documents the entrenchment of the Poudre's channel (Table 2), i.e., the degree to which the existing channel either contains or does not contain flood flows. It is easy to see that a few of the 17 cross sections exhibit fairly extreme entrenchment (ratios near 1), but most are not as entrenched, indicating that when high flows occur they have the potential to spread long horizontal distances. Indeed, the average entrenchment ratio is 16.8 and the average width of the flood prone area (defined as the channel width when the depth is double the maximum bankfull depth) is 1486 ft (453 m). This is substantial considering that the average bankfull width is only 94 ft (28.7 m). In other words, at high water, much of the Poudre River can escape far beyond its 'normal' boundaries, thus nurturing many existing wetland communities along its length.

Table 2. NISP DEIS Table 3-8, page 3-23.

Reach	Cross Section	2-year Discharge (cfs)	Bankfull Width (ft)	Bankfull Depth (ft)	Width/Depth Ratio	Width of Flood Prone Area (ft)	Entrenchment Ratio	Average Channel Slope (ft/ft)	Average Sinuosity	Average Meander Width Ratio	Bed Material (D50-mm)	Stream Type
Laporte	265046	1,827	84	4.4	19.2	846	10.1	0.0047	1.11	7.0	209.0	C3
	255598	1,827	103	3.4	30.0	145	1.41	0.0047	1.11	7.0	168.1	F3
Fort Collins	238183	1,542	166	2.1	79.1	179	1.1	0.0037	1.13	4.9	103.0	F3
	206947	1,817	90	6.7	13.5	597	6.6	0.0037	1.13	4.9	56.0	C4
Timnath	198987	1,582	70	4.7	15.1	471	6.7	0.0021	1.34	12.7	94.8	C3
	183254	1,582	97	3.5	27.8	1286	13.2	0.0021	1.34	12.7	38.1	C4
	159000	1,582	125	3.2	39.2	823	6.6	0.0021	1.34	12.7	42.9	C4
Windsor	136450	1,358	100	3.7	27.3	1500	14.9	0.0013	1.58	13.9	1.4	C5
	122435	1,358	100	5.2	19.4	3757	37.4	0.0013	1.58	13.9	27.7	C4
Greeley Upstream	97855	1,358	121	3.3	36.7	3438	28.4	0.0010	1.65	15.1	4.5	C4
	75931	1,353	68	4.6	14.8	4021	59.2	0.0010	1.65	15.1	1.0	C5
Greeley Channelized	50649	1,353	107	4.6	23.1	1500	14.0	0.0015	1.14	7.2	22.3	C4
	48457	1,353	103	2.6	39.2	255	2.5	0.0015	1.14	7.2	45.0	C4
	32153	1,353	78	3.9	19.9	88	1.1	0.0015	1.14	7.2	0.1	F5
Greeley Downstream	12901	1,446	78	3.8	20.7	3083	39.7	0.0012	1.19	11.1	1.2	C5
	6936	1,446	81	4.9	16.6	2879	35.6	0.0012	1.19	11.1	1.2	C5
	3463	1,446	57	3.6	16.0	398	7.0	0.0012	1.19	11.1	1.2	C5

Further, it is known that in areas adjacent to the Poudre River, groundwater elevations generally are closely tied to the river's existing water level (i.e., depth to groundwater will typically vary due to the depth of flow in the river). Fluctuations in groundwater levels of up to several feet should be expected along the river during periods of increased precipitation and runoff (USACE, 2008).

Methods

In order to estimate the impact of the proposed NISP on riparian wetlands and forests along the Poudre River, we have taken the following steps. Broadly speaking, these steps are: 1) map the riparian areas throughout the Poudre River corridor and nearby South Platte basin; 2) tabulate those riparian areas and wetlands within certain elevation zones surrounding the Poudre River's channel; 3) identify representative high and low estimates for the acreage of those habitat types likely to be degraded to some degree by the NISP; and 4) refine the estimate of likely impacts to the riparian acreage along the Poudre River by considering the likelihood of various biophysical processes.

Step 1. We gathered the digitized riparian data. The Colorado Natural Heritage Program carefully mapped and digitized the riparian areas along and near the Poudre River, and below on the South Platte, in strict accordance with the National Wetlands Inventory (NWI) mapping standards and quality control using current (2009) color infrared imagery (Carlson and Lemly, 2011). For our purposes here, we summarize the results of the NWI mapping in Table 3 that shows the wetland types and their attributes. Note that only the first four groups in Table 3 (forested, scrub-shrub, marshes swamps and wet meadows, and ponds and pondshores) are wetlands as defined by the US Fish and Wildlife Service. The next three groups (lakes and lakeshores, intermittently flowing canals and channels, and rivers and streams) are standard NWI additions that are primarily unvegetated deep water habitats. The final class, simply noted as 'riparian areas', include riparian forests not classified as true wetlands, at least under the current river flow regime, but still critically important in the overall habitat mosaic and likely river-dependent at least to some degree. In this report, we will not distinguish between modified and unmodified wetlands or riparian areas. Though the deep water wetland types offer a valuable diversity of habitats in our otherwise semi-arid environment, we do not believe that they are as peak flow-dependent as the other wetlands and riparian areas and we ignore them in the remainder of this report. Sources of accuracy and uncertainty are discussed in Carlson and Lemly (2011).

Table 3. Mapped wetland and riparian areas in the entire study area by major NWI code group and percent modified. Count means the total number of wetland polygons of each type. Modified means artificially constructed or in some way modified by humans to greater or lesser degrees, e.g., ponds in golf courses, canals, etc. See Carlson and Lemly (2011) for definitions and further breakdowns.

NWI Group	*Count*	*Mean Acres*	*Sum Acres*	*Acres Modified*	*Acres Natural*	*% Modified*
Forested Wetlands	524	3.2	1,666	8	1,658	.5
Scrub-Shrub Wetlands	1,680	1.4	2,300	24	2,276	1.0
Marshes, Swamps and Wet Meadows	6,139	1.8	11,049	1,420	9,629	12.9
Ponds and Pondshores	3,025	1.6	4,749	3,813	936	80.3
Lakes and Lakeshores	228	82.3	18,770	18,684	86	99.5
Intermittently Flowing Canals and Channels	318	7.7	1,639	1,635	4	99.8
Rivers/Riverbanks and Stream/Streambanks and Bars	659	5.3	2,555	0	2,555	0
Riparian Areas	4,499	3.9	13,669	34	13,635	.2
TOTAL	**15,827**		**56,397**	**25,617**	**30,779**	**45.4**

Step 2. The second step in our analysis was to develop a method to isolate areas above the river channel in regular elevation increments to match a variety of anticipated stage changes and other physical processes discussed later. We developed a GIS model to perform this work (PetersonGIS, 2012; and attached as an appendix). In brief, the following sub-steps outline what was accomplished:

A. The NWI wetlands and riparian areas from Step 1 were restricted to those that are adjacent to the Poudre River in Larimer and Weld counties below the North Fork of the Poudre River. In other words, all wetlands along the South Platte and other more distant features, such as Horsetooth and other plains reservoirs, were excluded.

B. Identify a set of cells up (and outward) from the cells representing the river channel by a 0.5 foot increment and calculate the area of each wetland and riparian type contained within this +0.5 foot elevation zone.

C. Repeat step B in +0.5 foot increments until the last zone includes elevations 10 feet above the river. (We had previously estimated that 10 feet should more than cover the elevation zones we wished to examine further. For reasons explained later, in this report we have only used data up to the 6.5-foot level.)

The result of this analysis is a table of acreage by wetland and riparian type within each of the elevation zones surrounding and "stepping up" from the river (Table 4). This technique can be visualized by examining Figure 2 showing a portion of the study area south of Windsor, Colorado. Several sources of site-specific inaccuracy were identified in this analysis given the nature of the raw data and the inherent limitations of using and adhering to the 10m x 10m grid of the National Elevation Data set. Realistically, we expect that the acreage of riparian areas and wetlands will be overestimated in some locales and underestimated in others, but with the total representing the average condition for the study area.

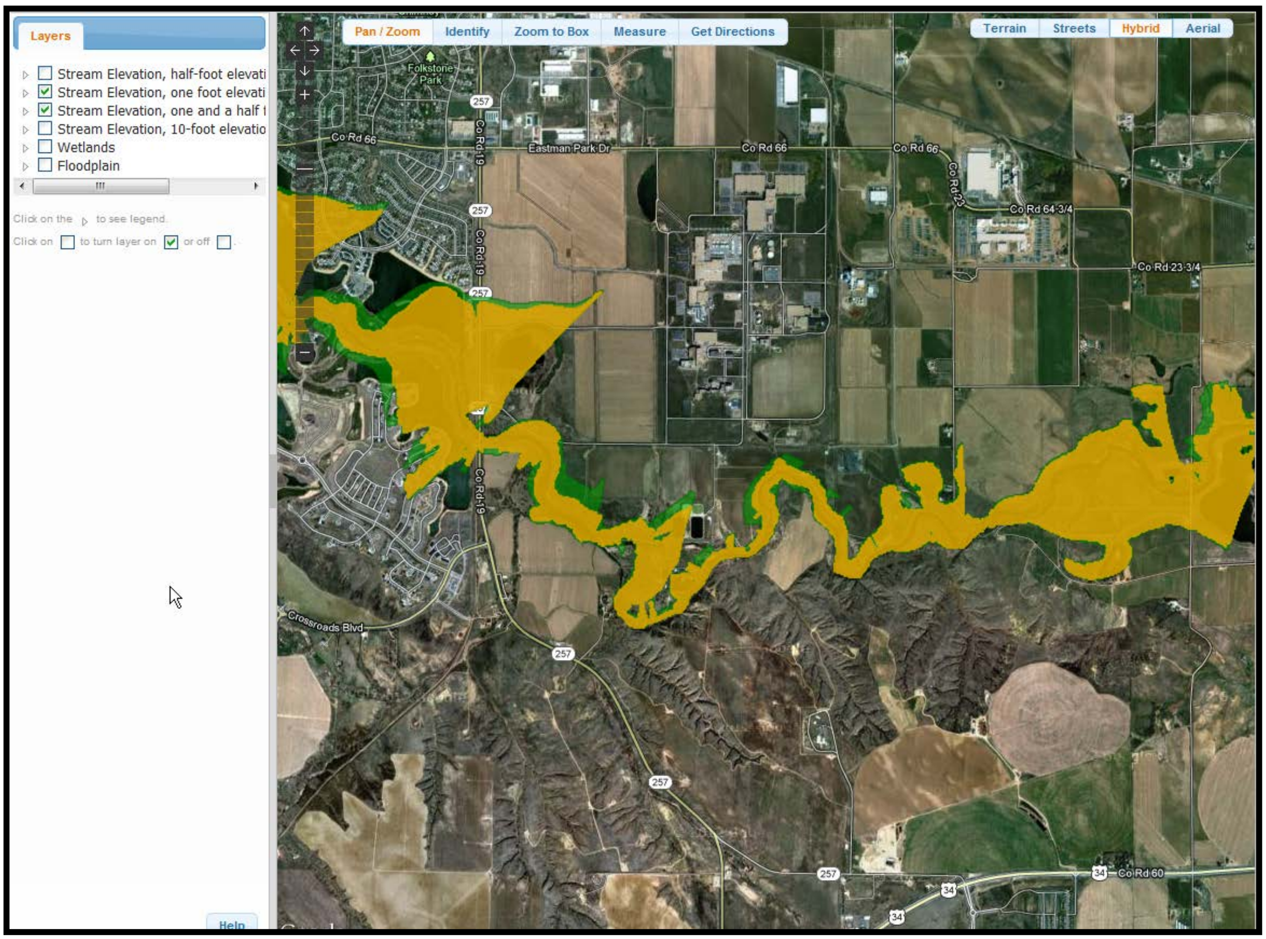

Figure 2. A portion of the Poudre River corridor study area illustrating land inundated by a 1.0 foot rise surrounding the river channel (mustard color) and the next elevation zone (green) demarking the 1.5 foot level.

Table 4. Results of our GIS "step-up" model by habitat type considered in our model. Area is given in cumulative acres up to and including the given elevation zone. Units are acres rather than hectares as in PetersonGIS (2012). Deepwater habitats, canals, and channels have been excluded. Our model indicates that the bolded subtotals from the column headed by 1.5 feet represent the likely minimum acreage affected by NISP (Step 3a); subtotals from the column headed by 6.5 feet represent the likely maximum acreage affected by NISP (Step 3b).

	Elevation increment above streamline, in feet									
Habitat type	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Modified Marshes, Swamps and Wet Meadows	22.9	29.3	35.1	40.6	49.7	54.2	61.3	66.0	71.1	75.2
Modified Scrub-Shrub Wetlands	12.8	13.5	14.3	14.8	15.4	16.0	16.4	17.2	17.6	17.9
Natural Forested Wetlands	79.5	90.1	100.0	108.1	118.6	124.4	130.6	134.5	138.8	141.7
Natural Marshes, Swamps and Wet Meadows	198.5	238.4	291.0	315.6	347.5	374.2	414.2	437.9	458.8	477.5
Natural Scrub-Shrub Wetlands	64.2	74.4	86.1	96.5	111.5	118.0	129.2	136.9	144.3	151.4
Wetland Subtotal	377.9	445.7	**526.5**	575.5	642.7	686.9	751.7	792.5	830.6	863.8
Modified Riparian	4.3	5.3	6.7	7.2	8.3	8.4	10.1	10.2	11.0	11.0
Natural Riparian	671.9	806.9	887.5	954.4	1005.8	1037.7	1065.8	1091.7	1115.5	1139.7
Riparian Subtotal	676.2	812.3	**894.1**	961.7	1014.1	1046.1	1075.9	1101.8	1126.5	1150.8

	Elevation increment above streamline, in feet									
Habitat type	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Modified Marshes, Swamps and Wet Meadows	79.6	82.4	87.9	91.6	97.5	101.5	105.4	108.3	112.7	116.0
Modified Scrub-Shrub Wetlands	18.1	18.2	18.3	18.5	18.6	18.6	18.7	18.8	19.0	19.1
Natural Forested Wetlands	148.7	151.9	157.8	163.2	166.4	169.1	171.0	172.8	174.4	175.7
Natural Marshes, Swamps and Wet Meadows	499.7	517.2	534.4	544.6	558.0	564.7	594.7	603.8	625.6	633.0
Natural Scrub-Shrub Wetlands	157.0	161.2	165.5	172.9	176.7	180.8	183.9	185.5	187.2	189.5
Wetland Subtotal	903.1	930.9	**963.9**	990.7	1017.2	1034.7	1073.7	1089.2	1118.9	1133.4
Modified Riparian	11.0	11.0	11.4	11.7	12.5	12.7	12.8	12.8	12.8	12.8
Natural Riparian	1159.8	1178.3	1194.9	1208.5	1220.2	1230.7	1243.2	1251.6	1261.9	1268.5
Riparian Subtotal	1170.9	1189.3	**1206.2**	1220.2	1232.7	1243.3	1256.0	1264.3	1274.6	1281.3

Step 3a. Establishing a low estimate on the effect of NISP on riparian areas and wetlands

We know from the NISP DEIS that peak water levels in the river would drop if NISP/Glade were built as described. The DEIS predicts that monthly average gage height declines will range from zero to about -1.5 ft, depending on the month, water year type, and location along the river. Declines representative of those most likely to adversely impact riparian wetlands were estimated at -1.66 ft at the Lincoln gage and -1.46 ft at the Greeley gage, both in June of a wet year under Alternative 2, and up to -1.77 ft under Alternative 3 (Table 5).

Note that we would far prefer to work with anticipated changes in *peak* flow stage rather than *average monthly* stage changes since peak flow stage changes are almost assuredly greater than monthly average stage changes and would better describe the hydrologic changes affecting streamside vegetation. We would also prefer to know any change in peak flow *duration* in addition to short-term stage heights because the duration would strongly influence the percolation volume. Unfortunately, we are unaware of these estimates being available.

Similarly, we would have preferred to use anticipated stage changes all along the river rather than solely at existing stream gaging locations (Table 5). However, we are unaware that any other stage data are available, so we must rely on what is available and attempt to deal with the issues raised in a later section of this report.

Table 5. NISP DEIS Table A-3 providing monthly average gage heights at a variety of locations along the Poudre River. Circled are the maximum monthly stage changes at the Lincoln Ave. gage referred to in this report.

AVERAGE GAGE HEIGHT (FT)

Alternative 2: Glade Reservoir + South Platte Water Conservation Project

LINK	TYPE OF FLOW AND REPRESENTATIVE YEAR		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
CANGAGE	Baseline Gage Height	Wet Year	2.06	1.99	1.99	2.00	2.01	2.27	3.59	4.46	3.62	3.04	2.54	2.31
		Avg.Year	2.12	2.01	1.94	1.96	1.99	2.24	3.32	4.11	3.29	2.90	2.38	2.24
		Dry Year	2.08	1.99	1.93	1.95	2.00	2.22	3.20	3.68	3.00	2.70	2.23	2.07
	Project Gage Height	Wet Year	2.05	1.96	1.94	1.95	1.97	2.23	3.38	3.87	3.46	2.98	2.51	2.29
		Avg.Year	2.11	1.99	1.92	1.96	1.97	2.17	3.05	3.75	3.14	2.86	2.39	2.26
		Dry Year	2.07	1.99	1.92	1.94	1.98	2.15	3.02	3.50	2.89	2.68	2.23	2.06
	Change in Gage Height	Wet Year	-0.01	-0.04	-0.05	-0.04	-0.03	-0.04	-0.22	-0.59	-0.15	-0.06	-0.03	-0.03
		Avg.Year	-0.01	-0.02	-0.02	-0.01	-0.02	-0.07	-0.27	-0.36	-0.15	-0.04	0.00	0.02
		Dry Year	-0.01	-0.01	-0.01	-0.01	-0.02	-0.07	-0.18	-0.18	-0.11	-0.02	0.00	-0.01
	Percent Difference	Wet Year	-0.5%	-1.9%	-2.5%	-2.1%	-1.7%	-1.7%	-6.0%	-13.1%	-4.3%	-1.8%	-1.2%	-1.1%
		Avg.Year	-0.6%	-1.2%	-1.1%	-0.3%	-0.8%	-3.2%	-8.0%	-8.7%	-4.6%	-1.4%	0.1%	0.7%
		Dry Year	-0.4%	-0.3%	-0.4%	-0.7%	-1.0%	-2.9%	-5.6%	-4.8%	-3.6%	-0.9%	0.0%	-0.7%
LINCGAGE	Baseline Gage Height	Wet Year	1.60	1.61	1.56	1.58	1.51	1.63	2.95	4.71	3.14	2.07	1.47	1.60
		Avg.Year	1.64	1.57	1.46	1.45	1.40	1.46	2.76	3.80	2.74	1.38	1.41	1.74
		Dry Year	1.60	1.61	1.43	1.45	1.34	1.38	2.54	2.98	1.91	1.60	1.37	1.53
	Project Gage Height	Wet Year	1.57	1.56	1.41	1.42	1.48	1.65	2.31	3.05	2.74	1.76	1.47	1.59
		Avg.Year	1.59	1.53	1.39	1.40	1.40	1.44	1.90	2.84	2.21	1.34	1.41	1.74
		Dry Year	1.55	1.57	1.39	1.36	1.34	1.38	1.82	2.38	1.53	1.51	1.37	1.50
	Change in Gage Height	Wet Year	-0.02	-0.05	-0.15	-0.16	-0.03	0.01	-0.64	-1.66	-0.40	-0.31	0.00	-0.01
		Avg.Year	-0.05	-0.04	-0.07	-0.05	0.00	-0.03	-0.86	-0.96	-0.53	-0.04	0.00	0.00
		Dry Year	-0.06	-0.04	-0.04	-0.09	0.00	0.00	-0.72	-0.60	-0.39	-0.08	0.00	-0.03
	Percent Difference	Wet Year	-1.6%	-3.3%	-9.7%	-10.3%	-2.2%	0.9%	-21.8%	-35.2%	-12.8%	-15.2%	0.0%	-0.6%
		Avg.Year	-2.9%	-2.5%	-4.8%	-3.4%	0.0%	-1.8%	-31.1%	-25.3%	-19.3%	-2.9%	0.1%	0.0%
		Dry Year	-3.5%	-2.5%	-2.7%	-6.1%	0.0%	0.1%	-28.3%	-20.2%	-20.2%	-5.3%	-0.1%	-1.9%
GRLYGAGE	Baseline Gage Height	Wet Year	2.16	2.12	2.08	2.09	2.20	2.37	2.39	4.14	1.85	1.85	2.03	2.29
		Avg.Year	2.17	2.09	2.02	2.09	2.21	2.22	2.07	2.99	1.75	1.72	1.93	2.27
		Dry Year	2.12	2.12	2.00	2.09	2.16	2.11	1.72	1.96	1.68	1.67	1.89	2.04
	Project Gage Height	Wet Year	2.17	2.12	2.07	2.11	2.22	2.40	2.24	2.68	1.85	1.85	2.03	2.30
		Avg.Year	2.17	2.09	2.05	2.10	2.24	2.22	1.82	2.41	1.74	1.72	1.93	2.26
		Dry Year	2.13	2.12	2.01	2.10	2.18	2.12	1.72	1.96	1.66	1.70	1.89	2.02
	Change in Gage Height	Wet Year	0.01	0.00	-0.01	0.02	0.02	0.03	-0.15	-1.46	0.00	0.00	0.00	0.00
		Avg.Year	0.00	0.00	0.02	0.01	0.03	0.01	-0.25	-0.58	-0.01	0.00	0.00	0.00
		Dry Year	0.00	0.01	0.01	0.01	0.02	0.01	0.00	0.00	-0.02	0.02	0.00	-0.02
	Percent Difference	Wet Year	0.3%	0.1%	-0.3%	0.9%	0.8%	1.4%	-6.4%	-35.3%	0.1%	0.0%	0.0%	0.1%
		Avg.Year	0.1%	0.0%	1.1%	0.5%	1.2%	0.4%	-12.0%	-19.5%	-0.3%	0.1%	0.0%	-0.2%
		Dry Year	0.2%	0.3%	0.7%	0.7%	1.0%	0.4%	0.0%	-0.1%	-1.2%	1.3%	0.0%	-0.8%
KRSYGAGE	Baseline Gage Height	Wet Year	4.22	4.14	4.20	4.32	4.27	4.63	5.81	6.98	4.37	4.24	4.31	4.54
		Avg.Year	4.30	4.13	4.17	4.30	4.34	4.31	4.80	5.15	3.97	3.68	3.94	4.13
		Dry Year	4.07	4.00	4.05	4.28	4.30	4.03	3.92	3.98	3.32	3.37	3.62	3.75
	Project Gage Height	Wet Year	4.14	4.09	4.13	4.26	4.24	4.61	5.72	6.67	4.31	4.21	4.23	4.51
		Avg.Year	4.26	4.08	4.07	4.22	4.31	4.29	4.68	4.92	3.94	3.67	3.88	4.09
		Dry Year	4.00	3.94	3.96	4.22	4.24	4.01	3.86	3.94	3.31	3.38	3.59	3.73
	Change in Gage Height	Wet Year	-0.08	-0.05	-0.07	-0.06	-0.03	-0.02	-0.09	-0.32	-0.05	-0.02	-0.08	-0.03
		Avg.Year	-0.04	-0.05	-0.10	-0.08	-0.03	-0.02	-0.12	-0.24	-0.03	-0.01	-0.06	-0.04
		Dry Year	-0.07	-0.06	-0.09	-0.07	-0.06	-0.01	-0.06	-0.04	-0.01	0.00	-0.03	-0.02
	Percent Difference	Wet Year	-1.8%	-1.3%	-1.7%	-1.4%	-0.7%	-0.5%	-1.5%	-4.5%	-1.2%	-0.6%	-1.8%	-0.6%
		Avg.Year	-0.9%	-1.2%	-2.5%	-1.9%	-0.7%	-0.6%	-2.4%	-4.6%	-0.7%	-0.3%	-1.4%	-1.0%
		Dry Year	-1.8%	-1.6%	-2.2%	-1.5%	-1.3%	-0.3%	-1.6%	-1.0%	-0.3%	0.1%	-0.8%	-0.4%

Alternative 3: Cactus Hill Reservoir + South Platte Water Conservation Project

LINK	TYPE OF FLOW AND REPRESENTATIVE YEAR		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
CANGAGE	Baseline Gage Height	Wet Year	2.06	1.99	1.99	2.00	2.01	2.27	3.59	4.46	3.62	3.04	2.54	2.31
		Avg.Year	2.12	2.01	1.94	1.96	1.99	2.24	3.32	4.11	3.29	2.90	2.38	2.24
		Dry Year	2.08	1.99	1.93	1.95	2.00	2.22	3.20	3.68	3.00	2.70	2.23	2.07
	Project Gage Height	Wet Year	2.05	1.96	1.94	1.95	1.97	2.23	3.34	3.85	3.45	2.98	2.51	2.28
		Avg.Year	2.11	1.98	1.92	1.95	1.98	2.17	3.04	3.75	3.12	2.86	2.38	2.25
		Dry Year	2.07	1.99	1.92	1.94	1.98	2.18	3.01	3.50	2.89	2.66	2.22	2.05
	Change in Gage Height	Wet Year	-0.01	-0.04	-0.05	-0.04	-0.04	-0.04	-0.25	-0.61	-0.17	-0.05	-0.03	-0.03
		Avg.Year	-0.01	-0.03	-0.02	-0.01	-0.01	-0.07	-0.27	-0.36	-0.16	-0.04	0.00	0.01
		Dry Year	-0.01	-0.01	-0.01	-0.02	-0.02	-0.04	-0.18	-0.18	-0.11	-0.04	-0.01	-0.02
	Percent Difference	Wet Year	-0.4%	-1.8%	-2.5%	-2.1%	-1.9%	-1.7%	-7.0%	-13.7%	-4.6%	-1.8%	-1.2%	-1.2%
		Avg.Year	-0.6%	-1.3%	-1.1%	-0.6%	-0.4%	-3.1%	-8.3%	-8.8%	-5.0%	-1.4%	0.0%	0.4%
		Dry Year	-0.4%	-0.3%	-0.4%	-0.8%	-1.0%	-1.7%	-5.7%	-4.8%	-3.6%	-1.5%	-0.5%	-1.0%
LINCGAGE	Baseline Gage Height	Wet Year	1.60	1.61	1.56	1.58	1.51	1.63	2.95	4.71	3.14	2.07	1.47	1.60
		Avg.Year	1.64	1.57	1.46	1.45	1.40	1.46	2.76	3.80	2.74	1.38	1.41	1.74
		Dry Year	1.60	1.61	1.43	1.45	1.34	1.38	2.54	2.98	1.91	1.60	1.37	1.53
	Project Gage Height	Wet Year	1.57	1.56	1.43	1.41	1.48	1.63	2.24	2.94	2.70	1.75	1.47	1.59
		Avg.Year	1.59	1.54	1.40	1.40	1.40	1.42	1.85	2.77	2.20	1.34	1.41	1.74
		Dry Year	1.55	1.59	1.41	1.38	1.34	1.38	1.85	2.39	1.53	1.46	1.37	1.50
	Change in Gage Height	Wet Year	-0.02	-0.05	-0.13	-0.16	-0.04	0.00	-0.71	-1.77	-0.44	-0.33	0.00	-0.01
		Avg.Year	-0.05	-0.03	-0.06	-0.05	-0.01	-0.04	-0.91	-1.02	-0.54	-0.04	0.00	0.00
		Dry Year	-0.06	-0.02	-0.02	-0.07	0.00	0.00	-0.70	-0.59	-0.38	-0.13	0.00	-0.03
	Percent Difference	Wet Year	-1.4%	-3.3%	-8.5%	-10.4%	-2.6%	0.0%	-24.2%	-37.6%	-14.0%	-15.7%	0.0%	-0.6%
		Avg.Year	-2.8%	-2.2%	-4.1%	-3.4%	-0.5%	-2.8%	-32.9%	-26.9%	-19.8%	-2.8%	0.1%	0.2%
		Dry Year	-3.5%	-1.2%	-1.5%	-4.5%	0.0%	0.1%	-27.4%	-19.8%	-20.1%	-8.4%	-0.1%	-1.9%
GRLYGAGE	Baseline Gage Height	Wet Year	2.16	2.12	2.08	2.09	2.20	2.37	2.39	4.14	1.85	1.85	2.03	2.29
		Avg.Year	2.17	2.09	2.02	2.09	2.21	2.22	2.07	2.99	1.75	1.72	1.93	2.27
		Dry Year	2.12	2.12	2.00	2.09	2.16	2.11	1.72	1.96	1.68	1.67	1.89	2.04
	Project Gage Height	Wet Year	2.16	2.12	2.07	2.11	2.22	2.39	2.14	2.65	1.85	1.85	2.03	2.29
		Avg.Year	2.17	2.09	2.04	2.10	2.24	2.22	1.81	2.37	1.74	1.72	1.93	2.26
		Dry Year	2.12	2.12	2.01	2.10	2.18	2.12	1.72	1.96	1.66	1.69	1.89	2.01
	Change in Gage Height	Wet Year	0.00	0.00	-0.01	0.02	0.02	0.03	-0.25	-1.48	0.00	0.00	0.00	0.00
		Avg.Year	0.00	0.00	0.02	0.01	0.03	0.00	-0.26	-0.63	-0.01	0.00	0.00	0.00
		Dry Year	0.00	0.00	0.01	0.01	0.02	0.01	0.00	-0.01	-0.02	0.02	0.00	-0.03
	Percent Difference	Wet Year	0.1%	0.0%	-0.4%	0.8%	0.7%	1.1%	-10.3%	-35.8%	0.0%	-0.1%	0.0%	0.1%
		Avg.Year	0.0%	-0.1%	0.9%	0.4%	1.1%	0.2%	-12.5%	-20.9%	-0.5%	0.0%	-0.1%	-0.2%
		Dry Year	0.1%	0.2%	0.6%	0.5%	0.9%	0.5%	0.0%	-0.3%	-1.4%	1.0%	-0.1%	-1.4%
KRSYGAGE	Baseline Gage Height	Wet Year	4.22	4.14	4.20	4.32	4.27	4.63	5.81	6.98	4.37	4.24	4.31	4.54
		Avg.Year	4.30	4.13	4.17	4.30	4.34	4.31	4.80	5.15	3.97	3.68	3.94	4.13
		Dry Year	4.07	4.00	4.05	4.28	4.30	4.03	3.92	3.98	3.32	3.37	3.62	3.75
	Project Gage Height	Wet Year	4.15	4.09	4.13	4.26	4.24	4.61	5.70	6.66	4.31	4.21	4.24	4.51
		Avg.Year	4.26	4.07	4.06	4.21	4.31	4.29	4.68	4.91	3.94	3.67	3.88	4.09
		Dry Year	4.00	3.93	3.96	4.21	4.25	4.01	3.86	3.94	3.31	3.37	3.59	3.73
	Change in Gage Height	Wet Year	-0.07	-0.05	-0.07	-0.06	-0.03	-0.02	-0.10	-0.33	-0.05	-0.02	-0.07	-0.03
		Avg.Year	-0.04	-0.06	-0.10	-0.09	-0.03	-0.02	-0.12	-0.25	-0.03	-0.01	-0.06	-0.04
		Dry Year	-0.07	-0.07	-0.09	-0.07	-0.05	-0.02	-0.06	-0.04	-0.01	0.00	-0.03	-0.02
	Percent Difference	Wet Year	-1.8%	-1.3%	-1.7%	-1.4%	-0.7%	-0.5%	-1.8%	-4.7%	-1.2%	-0.5%	-1.7%	-0.6%
		Avg.Year	-0.9%	-1.4%	-2.5%	-2.0%	-0.8%	-0.6%	-2.5%	-4.8%	-0.7%	-0.3%	-1.5%	-1.0%
		Dry Year	-1.8%	-1.6%	-2.3%	-1.6%	-1.1%	-0.4%	-1.6%	-1.0%	-0.3%	0.1%	-0.8%	-0.5%

How often, and for how long, areas must be inundated to have a measurable effect on riparian communities is an open question. Auble et al. (2005) documented that plants classified as obligate wetland species typically occur on sites saturated to within 0.3 m of the surface at least 2 weeks every 2 years. However, even temporary inundation without anoxic conditions is important for nutrient cycling. In addition, some sites may be thoroughly wetted by capillary-derived groundwater or bankwater. Thus, other facultative wetland species may also be strongly influenced. In fact, others have argued that habitats on the boundary between dry and wet, like cottonwoods or moist meadows, may be the most vulnerable to permanently altered hydrology (e.g., Cooper et al., 2006).

As noted, the monthly average declines shown in Table 5 likely mask the magnitude of the true short-term (several day) water level drops when Glade's forebay would be filling with pumps running at maximum capacity. Even if we knew peak flow stage changes, however, we note that stage changes of that magnitude may have a duration that is not a single day. There may be more than one close-to-peak event, especially given the diurnal snowmelt cycle we so often see on the Poudre River (Figure 3) that may be expected to add to the duration that wetland soils would remain saturated and potentially anoxic, thus supplementing any water derived from return flows or other non-river-derived source. In low gradient areas especially, the effect of short term stage changes might easily persist for many days or weeks.

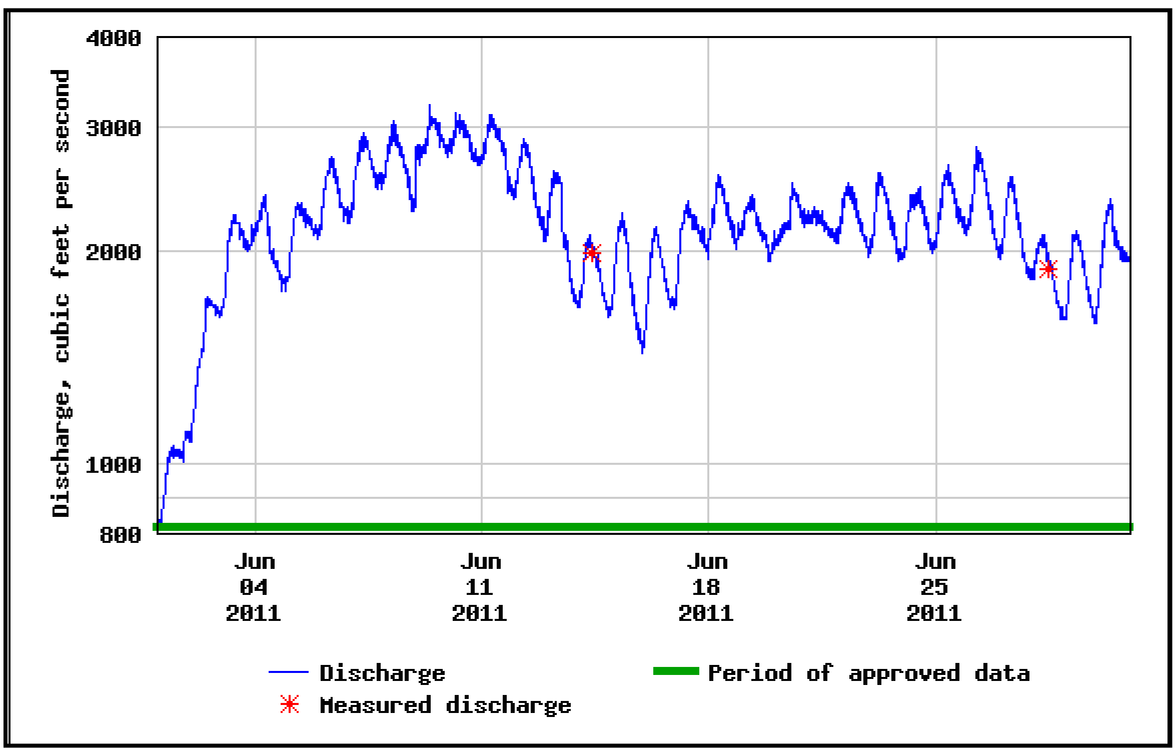

Figure 3. Example of diurnal peaks during snowmelt runoff for the Poudre River at Fort Collins. Source: USGS web portal.

How long saturation would actually occur at any given site remains unknown. We believe it is reasonable to surmise that NISP's short-term operations will alter the magnitude, frequency of recurrence, duration, and possibly timing of peak flow and inundation events along the river's course to the South Platte. For our purposes here, we assume an average inundation drop of -1.5 feet, a rounding of the values discussed previously from Table 5. Using the third column of Table 4, our model shows that the 1.5 foot drop in river stage level due to NISP would translate into 525 acres of wetlands (both modified and unmodified) and almost 900 acres of other riparian areas (both modified and unmodified) likely degraded over the long term. Therefore, a reasonable minimum estimate of NISP's direct causal adverse effect on wetlands and riparian areas would be at least 1420 acres.

Step 3b. Estimating a maximum effect.

We turn now from inundation as the direct wetting mechanism to moisture derived from capillary water through bank storage. We could approach this in two distinct ways, but they are interrelated.

First, how far away from the river would river-derived groundwater or bank storage be expected to exert a positive influence on wetland and riparian plant communities under current conditions. Galloway (2007), when examining the Poudre River ecosystem, initially suggests "within ten's of feet" but then acknowledges that the alluvial groundwater "100 feet or more" away from the river would also be affected, though perhaps to a lesser degree given precipitation and irrigation return flows. One hundred feet is about the same distance that Squillace (1996) observed river water moved horizontally into the bank, though in a much different physical setting. Even greater distances may be likely in areas where beaver have tunneled extensively into some of the steeper banks perpendicular to the river.

Second, we could consider moisture gradients arising from water stored in the bank and transmitted through capillary action to the various riparian vegetative communities. Some people may discount this mechanism. As humans have taken more water out of the Poudre River and distributed it throughout the watershed for irrigation, municipal and industrial uses, it has been argued in the NISP DEIS that more of the near-river wetland communities are no longer dependent on river flow but instead dependent solely on return flows.

Portions of the Poudre River may indeed be gaining such that groundwater elevations are usually perched above the stream. But other stretches of the river are assuredly losing reaches such that groundwater elevations usually slope downward away from the river's elevation into the nearby charging aquifer. Browne (2009) showed this, but this study only examined the river near Fort Collins. Farther downstream, Sjodin et al. (2001) have shown that high river discharges in the South Platte drainage are lost to the alluvium through bank storage at a rate that is linearly related to the logarithm of discharge. They surmised that high flows induced bank storage in the unsaturated portion of the alluvium.

We know that the Poudre River's gradient flattens from 0.0049 ft/ft upstream of Fort Collins to 0.0015 ft/ft downstream of Windsor (Figure 1) and the average particle size, both for the stream bed and the soil, becomes smaller in the downstream direction (Table 2). For example, the median particle size for bed material (D50, the diameter at which 50% of the particles are that size or smaller) declines significantly from over 200 mm near Laporte to about 1 mm near Greeley (Table 2). (Again, we would prefer to use soil data *outside* the channel, but we do not have these data so we default to Table 2 assuming that the subsurface particle size is similar given that the river has laterally swept the plains repeatedly over the millennia.) This means that it is easier for river-derived groundwater or bankwater to influence the soil moisture gradient ever farther from the river through both gravitational and capillary action. Such physical processes may be expected to add to the duration that wetland type soils will remain wet -- and occasionally anoxic -- and add to any water derived from return flows.

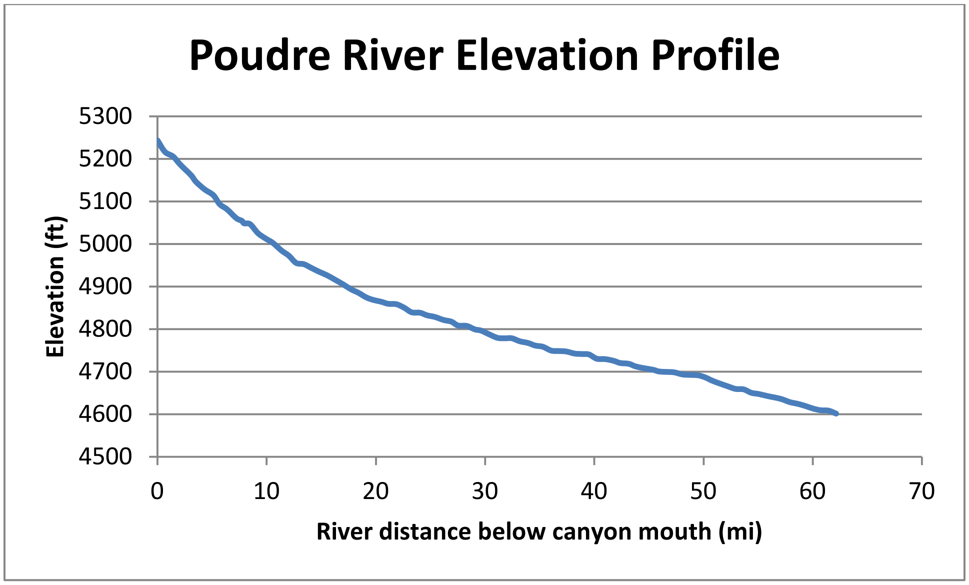

Figure 1. Approximate elevation profile for the plain's portion of the Poudre River.

In other words, we cannot rule out the influence of streamflow-influenced groundwater on wetlands and riparian areas especially in the lower portions of the Poudre River even if direct inundation does not occur and even if some wetlands and riparian forests receive a portion of their water from non-river sources.

The thickness of the capillary fringe can range from less than 10 cm in coarse cobbles to greater than 100 cm in fine silts (i.e., up to 3.3 ft), and successful vegetative establishment is documented to occur at elevations 0.6-2 m (i.e., up to 6.6 ft) above the late summer low flow river stage, depending on local conditions (Mahoney and Rood, 1998; Horton and Clark, 2001).

So in an attempt to put an absolute <u>upper bound</u> on potential direct effects on riparian wetlands along the Poudre, we assume that a change in river stage translates into a very similar elevation change in the top-most limit of capillary water. Therefore, we can use the 6.5 foot increment in Table 4 (rounding down from the 6.6 feet mentioned above) to estimate a maximum vertical influence derived from capillary action. Using the 6.5 foot increment in Table 4 reveals that about 960 acres of wetlands and 1200 acres of other riparian areas occur within that band, for a total of about 2170 acres.

Step 4. Refining the estimate.

We have identified two major sources of uncertainty in our model. First, although most riparian areas close to the river (and near its 'normal' elevation) may be expected to benefit from river-derived groundwater or bankwater, some riparian areas farther from the river may be only marginally affected by the NISP's anticipated stage reductions because they are sustained by precipitation and return flows. Similarly, though a few of the riparian areas perched 6.5 feet above the river may benefit from capillary action traceable to river-derived groundwater or bankwater, it seems unlikely that many of the perched areas would be significantly affected by NISP operations, especially if they are far removed from the river's banks. In other words, there may be purely *biophysical* reasons why some portion of the wetland communities within the elevation zones we have analyzed will not likely be affected by potential river stage changes.

Second, we have alluded to *methodological and data* reasons why we may be overestimating stage-influenced areas. The stage changes were predicted at gaging locations, several of which are located in incised channel areas such that stage changes in other unconfined reaches may not be as large, depending on localized channel roughness features such as vegetation, constrictions, and bends in the river. Other methodological and data reasons may also play a part. For example, the elevation of cells representing the river channel may be inaccurate in some areas where channel walls are steep, like where there are adjacent gravel pits[1]. Inaccuracies of this sort have the potential to exaggerate the area represented by the elevation zone adjacent to the river in the GIS analysis.

In order to account for biophysical probabilities and any methodological inaccuracy, we postulate that the probability of effect of stage change on wetland communities diminishes in each higher elevation band surrounding the river. For example, it may be reasonable to estimate that 95% of the riparian wetlands within the 0.5 foot elevation zone would exhibit direct effects arising from a 1.5 foot drop in peak stage, whereas only 1% of those wetlands perched 6.5 feet above the river may be degraded because of their presumed reliance on precipitation and return flows. It also seems reasonable (and conservative) to assume that the probability of effects drops off rather precipitously as one moves ever higher above the river due to declining frequency and duration of direct or indirect riverine influence such as inundation and capillary action. For example, the qualitative nature of the decline we postulate is supported by the shape of the relationship between evapotranspiration and depth to the water table as illustrated in Cooper et al. (2006). To that end, we expect something like an exponentially declining curve of probabilities as illustrated in Figure 5 that serves to integrate the variety of uncertainties we are dealing with. Note that the specific probabilities we employ here are best professional judgment since no empirical data are available.

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[1] The elevation data do, however, represent the elevation of the bare earth instead of the canopy of any vegetation. See http://ned.usgs.gov/Ned/faq.asp.

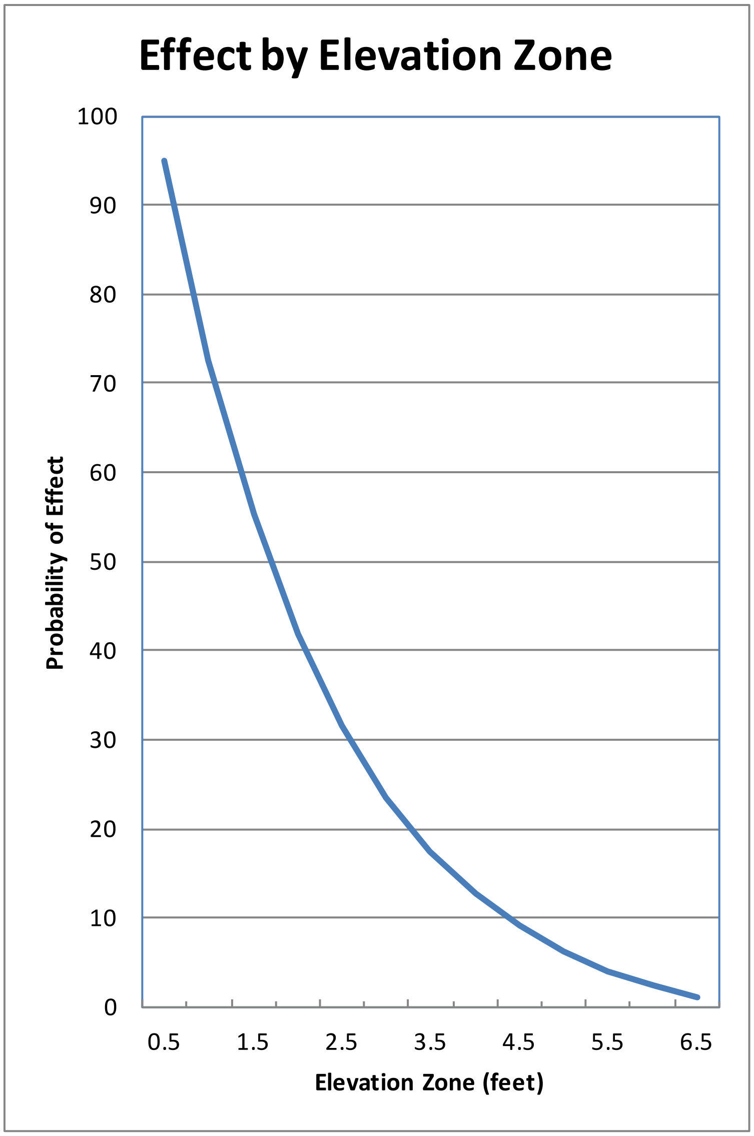

Figure 2. Proposed probability of wetlands and riparian areas being influenced by altering river stage in zones of increasing elevation surrounding the river. For example, we propose that wetlands located 1 foot above the cells defining the river channel only have a 73% probability of being affected by NISP's alteration of river stage.

Integrating the probabilities as shown in Figure 5 with the acreages given in Table 4 results in the acreages provided in Table 6. This integration estimates approximately 700 acres of wetlands and almost 1000 acres of other riparian areas would be degraded by reduced river stage, for a total of 1700 acres.

Table 6. Acres of riparian and wetland habitat types affected by anticipated NISP stage changes after factoring in likelihood of effects. "Probability of effect" refers to the postulated degree of effect, reflected in Figure 5. The probability of effect has been integrated using the stated probability times the incremental acres in that elevation zone, then totaling through each preceding elevation zone. In other words, acres are cumulative up to and including the zone for each column. Subtotals in the last column, 6.5 feet, is our best estimate of the extent of the effects of NISP.

	Probability of effect (%)												
	95	73	55	42	32	24	17	13	9	6	4	2	1
	Elevation increment above streamline, in feet												
Habitat type	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
Modified Marshes, Swamps and Wet Meadows	22	26	31	35	41	44	50	53	57	60	60	60	60
Modified Scrub-Shrub Wetlands	12	13	13	14	14	14	15	15	16	16	16	16	16
Natural Forested Wetlands	76	83	90	96	104	108	113	115	119	121	121	121	121
Natural Marshes, Swamps and Wet Meadows	189	218	256	274	297	316	345	362	377	391	392	392	392
Natural Scrub-Shrub Wetlands	61	68	77	84	95	100	108	114	119	124	124	125	125
Wetland Subtotal	359	408	467	502	551	583	630	660	687	712	713	714	**714**
Modified Riparian	4	5	6	6	7	7	8	8	9	9	9	9	9
Natural Riparian	638	736	795	843	881	904	924	943	960	978	979	979	979
Riparian Subtotal	642	741	801	849	888	911	932	951	969	987	988	988	**988**

Discussion

Western riparian communities are one of the most important habitat types in the west. They disproportionately contribute to local biodiversity, provide flood protection, and offer significant economic benefits to local communities. The Poudre River provides these same goods and services. Using a landscape-scale approach, we estimated how the NISP development would threaten these valuable plant communities by reducing rejuvenating peak flows throughout the river corridor, affecting the mosaic of riparian woodlands and wetlands to varying degrees depending on their height above (and distance from) the river, and whether they are likely to be inundated or solely receive capillary water from stream-supported water tables or bank storage. Our model provides a good faith estimate of the acreages of wetlands of various types that would likely be degraded by the NISP (Table 6).

We have shown that the total area of likely degraded wetlands is substantial when integrated over the length of the river that will experience reductions in peak flow stage. Thus, if NISP were built as described in the draft EIS, we can expect between 1420 and 2170 acres of wetlands and riparian areas, with a most likely estimate of 1700 acres, to be degraded by the project.

We are unaware that anyone has undertaken an analysis like this before. Our choice of a landscape scale (along 40 km of the Poudre River) allows us to make up for the inaccuracy at or near any specific location and enables us to competently generalize the expected wetland area degraded by NISP's projected reduction in peak flows. We have not counted all the potentially affected wetland areas: (1) wetland/riparian impacts along the Larimer-Weld and the New Cache canals, both left partially dewatered by NISP; (2) any wetlands and riparian areas farther down on the South Platte River where, even though projected stage changes would be far smaller, the areas adversely affected could cumulatively be large because of the number of stream miles; (3) wetland communities lining the fringes of gravel ponds adjacent to the Poudre River even though the water level in those ponds depends directly on river stage, though lagged in time (e.g., Hantush et al., 2002); (4) wetlands on in-river fluvial islands in the river channel; (5) wetlands supported, at least in part, by peak flows that percolate into the Poudre's paleo and abandoned channels, and may be far removed from today's channel; and (6) even more broadly, we have not yet counted impacts on wetland communities from removing almost 40,000 acre feet of water from the Poudre Basin as a whole.

There is not necessarily any reason to believe that changes due to NISP water withdrawals will only be incremental in nature. Many or most ecological systems exhibit threshold responses. Non-linear responses of riparian vegetation to alterations in flow regimes have indeed been documented (Shafroth et al., 2010). Predictions of climate change along Colorado's Front Range call for large increases in growing season evapotranspiration (USDI, BOR, 2012). If such changes come to pass, riparian zones – just like farmer's crops – will experience far more water stress than today, reducing their human and other ecological values, especially if they remain unprotected.

The conservation and restoration of cottonwood and other riparian wetland communities rely on provisions for adequate river flow regimes for survival, growth and sustainable reproduction (Rood et al., 2003; Auble et al., 2005). Human-induced modification of flow regimes has resulted in extensive alteration of riparian communities. Some of the adverse effects of altered flow regimes on vegetation may be reversed by restoring components of the natural flow regime (Merritt et al., 2010). Specifically, we advocate increasing the magnitude, frequency and duration of peak flows along the Poudre River.

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Appendix A

Wetlands Analysis: Inputs, Methods, Results

BY PetersonGIS

Wetlands Analysis

FOR Save the Poudre: Poudre Waterkeeper | BY PetersonGIS

Inputs, Methods, Results

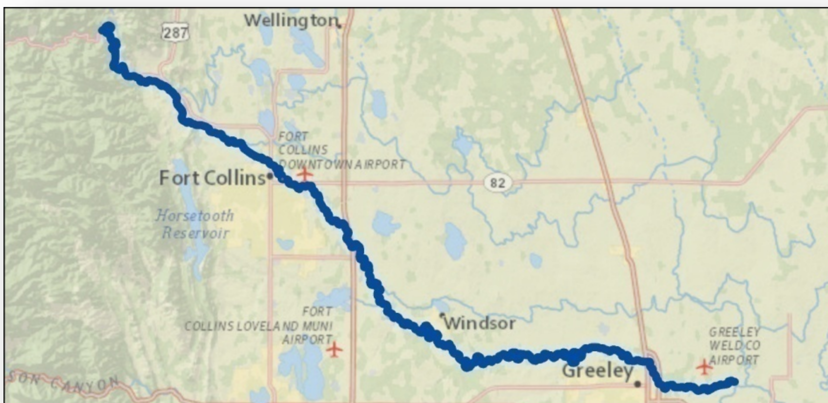
June 15, 2012

PROJECT GOALS

The project goals were 1) create variable width buffers along the Cache la Poudre River that represent half-foot increments in elevation change between the river streamline and the outer edge, from half-foot to ten feet and 2) calculate the total wetland area of each wetland type within each buffer.

STUDY AREA

The study area was the Cache la Poudre River, from its confluence with the North Fork Cache la Poudre River to its confluence with the South Platte River, as shown in dark blue, below.



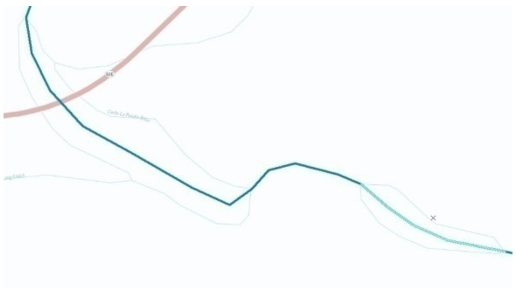
DATA

Elevation The 10 meter resolution National Elevation Dataset (NED) was used. The elevation values are in meters, with high precision (6 decimals). The data was mosaicked into a single grid. The data was then converted to an integer grid by multiplying the elevation values by 100, since an integer grid—rather than a floating point grid—was required in some of the GIS processing steps.

Streams Hydrography centerline data for the study area were received from the City of Greeley GIS Department and the Larimer County GIS Department. A few sections of the river were digitized by-eye using an Esri topography basemap at 1:5,000 scale. The sections where this was necessary were 1) a location where there was a gap in the hydrology and 2) a few small places where the original hydrography represented the outer banks of ponds rather than the centerlines.

1) Gap digitizing location shown by red arrow:

2) Stream centerline digitizing shown below:



Wetlands Wetlands data were received from Save the Poudre: Poudre Waterkeeper. Though the original wetland data extent included wetlands for portions of the South Platte River, these were excluded from the analysis as they were not in the study area. Identification of which wetlands were to be excluded was determined by eye. Where the Cache la Poudre River meets with the South Platte River, the South Platte River wetlands were identified and eliminated from processing by estimating the correct wetland connectivity from a hillshade basemap.

DATA ACCURACY

NED The NED has a reported 90% vertical accuracy confidence of 3.99 meters and 95% vertical accuracy confidence of 4.75 meters. This accuracy is for the coterminous U.S. The accuracy within the Save the Poudre: Poudre Waterkeeper study area may be more or less. However, it is reasonable to assume that while the absolute accuracy may be plus or minus 4 meters, it is also reasonable to assume that the accuracy between nearby pixels is much better; in other words, the level of incorrectness—precision—would be relatively consistent across a study area as small as this (small when compared to the coterminous U.S.).

Streams The stream data do not have a reported accuracy. However, the accuracy appears to be at least consistent with a map scale of 1:5,000.

Wetlands The wetlands polygons used in this study, and their associated methods and accuracy are described in *National Wetland Inventory (NWI) Mapping of the Cache la Poudre and South Platte Rivers*, Colorado Natural Heritage Program, Colorado State University, March 23, 2011.

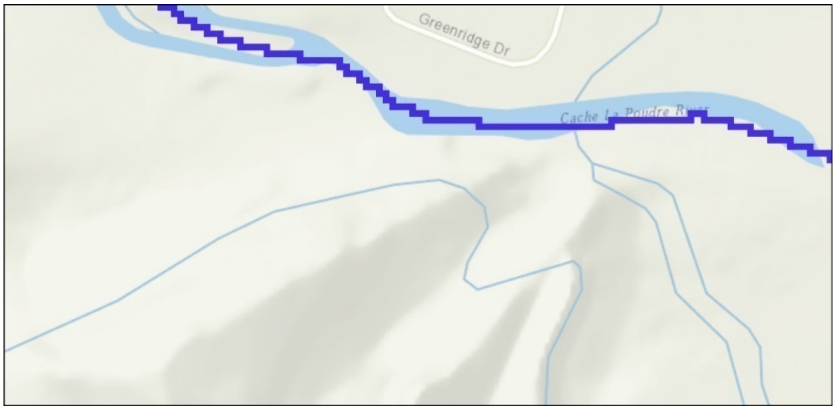
CALCULATING ELEVATION INCREMENT BANDS

The methods for creating the elevation increment bands are as follows. These steps illustrate the creation of the 3 foot buffer, as an example of creating any one elevation zone. The entire dataset is not shown, but rather zoomed into a segment of the river to better illustrate the process. The zoomed-in portion of the map used for the illustrations is shown outlined in a black rectangle in the following overview map:

The last step of the procedure was repeated, with the increment number (15 for 0.5', 30 for 1.0', 45 for 1.5' and so on) changing each time

1) The procedure began with a vector representation of the Cache la Poudre River centerline shown here as a dark blue line overlaid on a basemap:

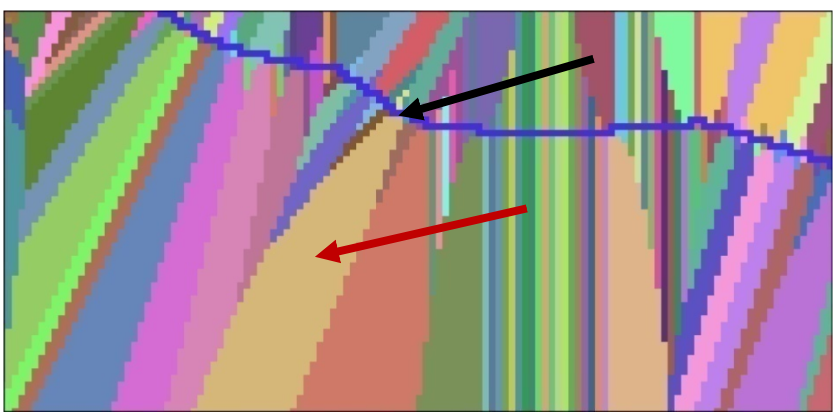
2) The vector river centerline was converted to a 10 meter resolution grid, where each grid cell was assigned the elevation of the NED at that location. The river centerline grid was the same size and extent as the NED, so that the grid cells were exactly aligned between the two datasets. The centerline grid is shown in purple:



3) Using the river centerline grid as the source grid, a Euclidean allocation grid covering the study area was created. In a Euclidean allocation operation, the software creates a new grid and, for each cell, determines which source cell (the closest river cell in this case) it is closest to and then assigns the value of that nearest cell to it.

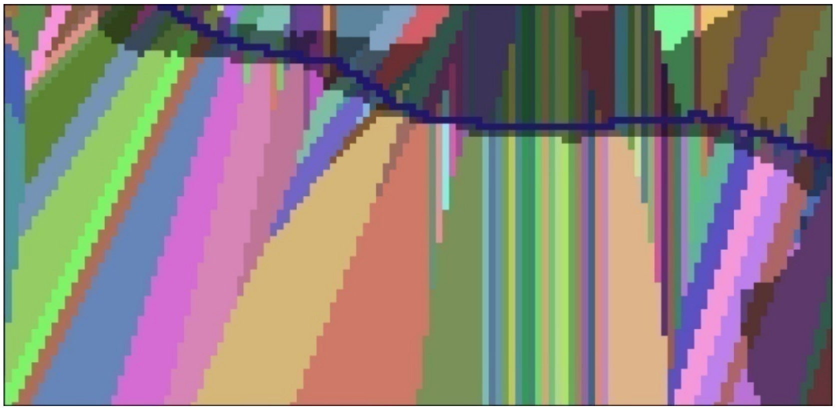
In doing this, the software will later be able to determine which starting elevation value to compare each cell to, in order to determine if each cell is within the three foot limit or not. The resulting grid is colored such that each color represents a different elevation value. It is easy to see from the illustration how the elevations are allocated outward from the source cells according to which source cell each is closest to.

For example, the black arrow points to one source cell with an elevation value of 154600 (this number represents meters, multiplied by 100). The red arrow points to the Euclidean allocation of all the other cells that were assigned 154600—in the tan section—because they were closest to that source cell.

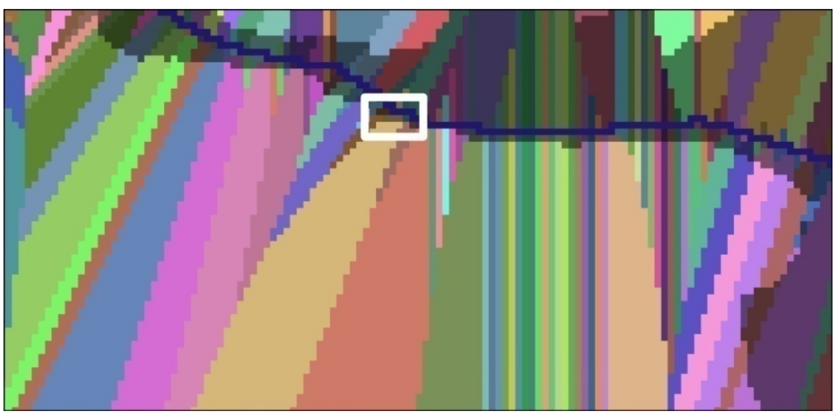


4) To delineate the 3 foot elevation increase buffer, for example, the elevation values of all the non-river cells need to be compared to the elevation values of their closest river cells. To do this, the software was programmed to subtract the Euclidean allocation grid from the original NED grid and determine whether the difference is greater than 3 feet or less than or equal 3 feet. Cells where the difference was less than or equal to 3 feet were included in the final buffer, the others were not.

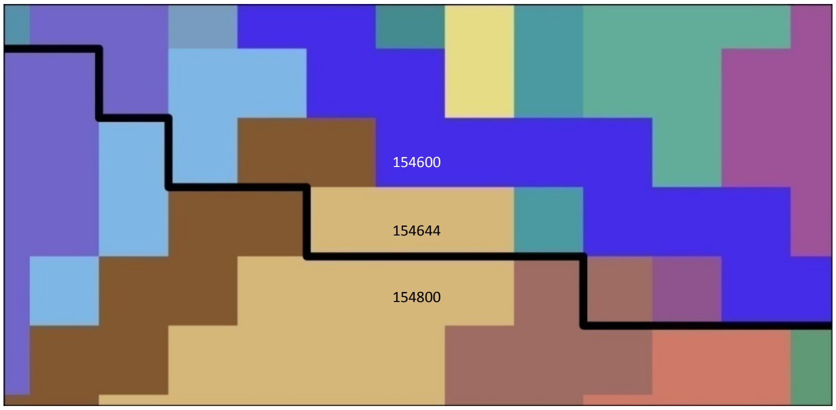
The 3 foot elevation increment buffer is shown below, in semi-transparent black.



To further illustrate the process, the map was zoomed-in to the area shown in the white rectangle below:



In the zoomed-in map, the 3 foot buffer is shown as a dark black line. The river source cell is labeled in white with its elevation value of 154600. The elevations of two nearby cells are labeled in black. Both of the nearby cells that are labeled are closest to the 154600 source cell. However, the 154800 cell is more than 3 feet above the source cell: 154800 – 154600 = 200, where 200/100 x 3.28 = 6.56 feet, which is above the 3 foot threshold for this elevation buffer. For the cell above it: 154644 – 154600 = 44, where 44/100 x 3.28 = 1.44 feet, which is within the 3 foot threshold for this elevation buffer.

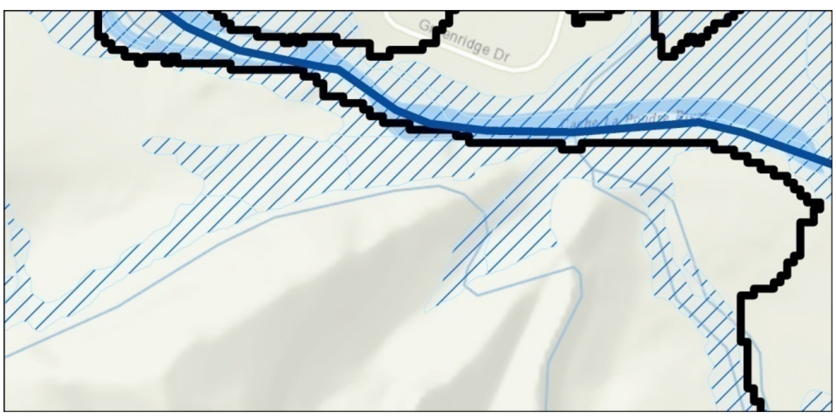


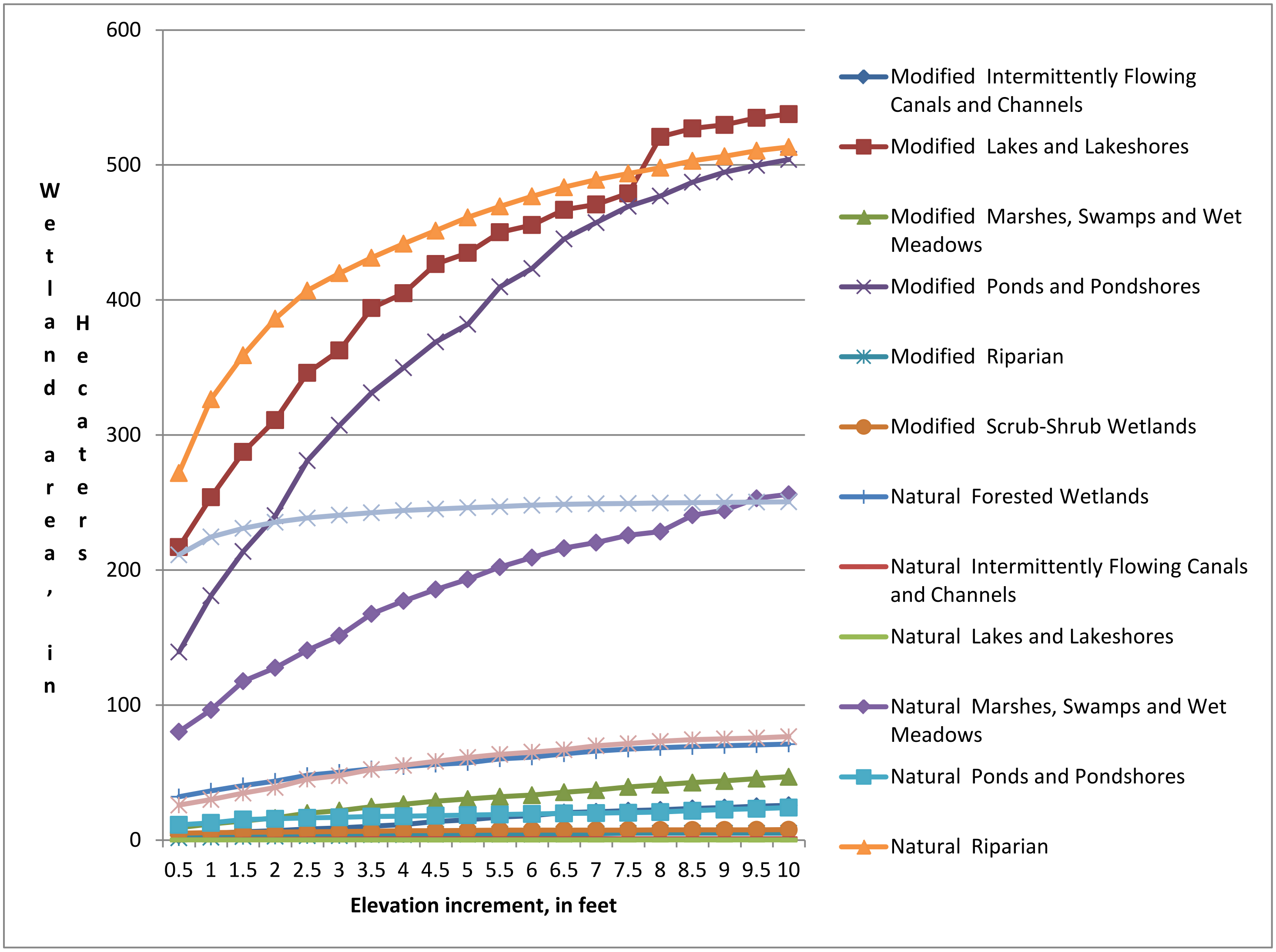
This step was repeated for all the elevation increments from half-foot to ten-feet, thus creating 20 progressively larger elevation increment buffers.

WETLAND AREA CALCULATIONS

The area of wetlands within each elevation increment buffer was computed with a zonal statistics operation. The operation sums the total area of wetlands, per each wetland category, in each elevation increment buffer. The following map shows the 3 foot elevation increase buffer as a black outline, the Cache la Poudre River as a dark blue line, and the wetlands—all wetland types shown as a blue-hatched area. For the 3 foot elevation increment buffer, only the blue-hatched area within the black line was counted.

The graph and table shown in this section report the wetland areas in hectares.




Wetland area, in Hecaters
0
100
200
300
400
500
600
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
Elevation increment, in feet
Modified Intermittently Flowing Canals and Channels
Modified Lakes and Lakeshores
Modified Marshes, Swamps and Wet Meadows
Modified Ponds and Pondshores
Modified Riparian
Modified Scrub-Shrub Wetlands
Natural Forested Wetlands
Natural Intermittently Flowing Canals and Channels
Natural Lakes and Lakeshores
Natural Marshes, Swamps and Wet Meadows
Natural Ponds and Pondshores
Natural Riparian

	Elevation increment, in feet									
Wetland Type	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Modified Intermittently Flowing Canals and Channels	3.63	5.01	6.1	7.12	8.31	9.17	10.28	11.65	13.85	14.96
Modified Lakes and Lakeshores	217.1	254.01	287.57	311.14	346.12	362.73	394.14	405.1	426.7	434.98
Modified Marshes, Swamps and Wet Meadows	9.26	11.87	14.22	16.42	20.1	21.95	24.79	26.7	28.78	30.44
Modified Ponds and Pondshores	139.35	181.07	213.83	240.34	281.13	307.32	331.34	349.91	369.02	382.08
Modified Riparian	1.75	2.16	2.7	2.93	3.35	3.38	4.09	4.12	4.46	4.46
Modified Scrub-Shrub Wetlands	5.16	5.48	5.78	5.99	6.24	6.48	6.63	6.95	7.12	7.26
Natural Forested Wetlands	32.19	36.45	40.46	43.74	47.99	50.34	52.87	54.45	56.16	57.36
Natural Intermittently Flowing Canals and Channels	0.29	0.48	0.63	0.67	0.81	0.83	0.94	0.95	0.98	1.03
Natural Lakes and Lakeshores	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Natural Marshes, Swamps and Wet Meadows	80.35	96.48	117.77	127.72	140.63	151.45	167.62	177.22	185.69	193.23
Natural Ponds and Pondshores	11.4	12.85	15.34	15.84	16.57	16.95	17.48	17.74	18.17	18.57
Natural Riparian	271.92	326.56	359.15	386.25	407.06	419.96	431.34	441.79	451.43	461.25
Natural Rivers/Riverbanks and Stream/Streambanks and Bars	211.32	224.61	230.95	235.45	238.6	240.76	242.51	244.15	245.22	246.24
Natural Scrub-Shrub Wetlands	25.97	30.09	34.84	39.05	45.13	47.75	52.29	55.4	58.4	61.28

	Elevation increment, in feet									
Wetland Type	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Modified Intermittently Flowing Canals and Channels	17.07	18.09	20.45	20.98	21.81	22.4	23.46	24.12	25.09	25.85
Modified Lakes and Lakeshores	450.26	455.62	466.86	470.82	478.99	520.87	527.15	529.73	534.98	537.71
Modified Marshes, Swamps and Wet Meadows	32.21	33.33	35.56	37.07	39.46	41.07	42.66	43.83	45.61	46.96
Modified Ponds and Pondshores	409.85	423.36	445.29	457.35	469.46	477.05	487.26	494.83	499.73	504.11
Modified Riparian	4.46	4.46	4.61	4.75	5.06	5.13	5.17	5.17	5.17	5.17
Modified Scrub-Shrub Wetlands	7.34	7.38	7.42	7.47	7.51	7.54	7.56	7.6	7.7	7.74
Natural Forested Wetlands	60.16	61.49	63.86	66.06	67.35	68.45	69.2	69.95	70.57	71.11
Natural Intermittently Flowing Canals and Channels	1.05	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Natural Lakes and Lakeshores	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Natural Marshes, Swamps and Wet Meadows	202.24	209.29	216.25	220.39	225.83	228.54	240.68	244.35	253.19	256.17
Natural Ponds and Pondshores	19.05	19.45	19.87	20.07	20.32	20.84	21.8	22.65	23.28	24.17
Natural Riparian	469.38	476.85	483.55	489.06	493.79	498.04	503.12	506.5	510.67	513.37
Natural Rivers/Riverbanks and Stream/Streambanks and Bars	247.02	248.02	248.75	249.17	249.38	249.67	249.92	250.23	250.41	250.61
Natural Scrub-Shrub Wetlands	63.52	65.24	66.99	69.96	71.49	73.15	74.42	75.06	75.74	76.69

OTHER METHODS

Other methods that are similar to the methods described in this paper include the following. These other methods were explored but ultimately not used for the reasons discussed:

Cost Distance The cost distance tools in GIS software are sometimes used to simulate floods, a similar goal to the one in this analysis (see descriptions on how this works here and here). In order to use the cost distance method, a stage surface elevation is needed. The stage surface elevation in this analysis' study area, however, varies as the terrain decreases downstream. As stated in the second article linked to above, the cost distance flood simulation process is a local level procedure and not applicable for a larger study area like the one in this analysis.

Transect Points As described here, a method of deriving transect points that emanate from stream centerline points has been used for modeling of riparian zones using digital elevation models and flood height data. In this method, the elevation values at points along transects are compared with the elevation values at the stream points that the transects emanate from. If they are above the user-set threshold then those points are not within the buffer. Points that are within the threshold are then connected to form the buffer. This procedure has the potential to create larger buffers because each cell is considered with more than a single source cell (the transects overlap), whereas the procedure in this analysis compared each cell to its single closest source cell. The Save the Poudre: Poudre Waterkeeper analysis is a more conservative estimate of the buffer than the transect points procedure.

Lake and Pond Amendment The Save the Poudre: Poudre Waterkeeper analysis could have been less conservative if the buffers were augmented with an existing lake and pond data layer. As it is, the buffers sometimes split lakes and ponds.

MODELING ACCURACY

Potential sources of inaccuracies, listed below, all point to the fact that this analysis is conservative in its identification of the elevation increment buffers. The buffers represent, as far as it is known, the smallest possible area within which the specified elevation increments occur.

Source Cells In this analysis, the source cells consisted of a one-cell-wide representation of the Cache la Poudre River centerline. Another possible source cell representation would have been to widen the centerline to two or more pixels, or to use river bank cells. Any of these possibilities would have increased the original elevation that all elevations were compared to, thus widening the resulting buffers. With regard to source cells, the one-cell-wide representation used in the study contributed to the conservative size (small, rather than including potentially inaccurate cells) of the buffers.

The river centerline locations posed a potential for inaccuracy. The location of the river centerline determines the source elevations that all other cells are compared to. However, the river centerlines were a higher resolution (1:5,000) than the NED data they were being compared to and converted to (10-meter).

The model only considers the closest source cell when comparing whether or not an elevation is above the elevation increment buffer threshold or below it. Source cells that are second-closest to comparison cells are not considered. Therefore, a situation can occur where a pixel that is diagonal—in the southeast direction, for example—to a source cell may have been within a half-foot from the northwestern source cell, but is not within half-foot from its closest cell—the one directly to the west of it. In this example case, the northwestern pixel would have to be a greater elevation than the western pixel (entirely possible given the downward nature of the river terrain). This example is shown below. The source cells are indicated in the shaded gray boxes. The cell with elevation of 154614 is within half-foot of the cell with elevation value 154600, but not within half-foot of the cell with value 154595.

154600	154620
154595	154614

Elevation units are in meters x 100

In this way, the resulting elevation increment buffers are conservative, and not as large as they might be if second-closest cells were also considered.

Euclidean Algorithm The Euclidean allocation algorithm has a potential source of error worth noting but is most likely insignificant across the study area. In cases where a pixel is equidistant between two source pixels, the algorithm assigns that pixel the elevation value of the first of the two source pixels that it encounters, and is basically arbitrary in these cases. Because the source river cells are only one-pixel wide, this occurs rarely.