Hydrologic Assessment of the Monkey River Watershed, Belize

Phase 1: Human Impact Mapping Along the Monkey River and its Main Tributaries

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Introduction

Riparian forests and their associated floodplains provide an important buffer for freshwater ecosystems against human impacts stemming from land use practices and land cover change. The removal of riparian forests decreases bank stability and the retention of both nutrients and sediments, alters the quality and quantity of organic matter in freshwater systems, increases light penetration and water temperature, and alters the hydrologic balance between runoff and evapotranspiration in the watershed (Allan 2004). The impact of riparian forest clearing on rivers can have varying effects depending on the specifics of human activities within a given river reach. Human impact mapping and the Expected Local Stress Intensity (ELSI) index seek to quantify the locations and frequencies of different riparian zone land uses and translate them into scores that estimate the intensity of stresses originating from a particular river segment (Esselman 2001). The technique represents a rapid and inexpensive alternative for natural resource managers and communicates spatially accurate information on human impacts to freshwater ecosystems.

Here we report on human impact mapping along the Monkey River and its main tributaries, the Bladen, Trio and Swasey Branches. The results of this work are part of a larger hydrologic assessment of the Monkey River watershed.

Study Area

The Monkey River is located on the southeastern flank of the Maya Mountains. The Monkey River watershed consists of three main branches (Bladen, Trio and Swasey) that join in the coastal plain and enter the Caribbean as a 6th order river (Fig 1) (Esselman et al. 2006). The Monkey River is the fourth-largest watershed in Belize (1275 km^2) and is the largest of the six watersheds (Rio Grande, Middle River, Golden Stream, and Deep River, and Monkey River) that together form the greater Port Honduras watershed.

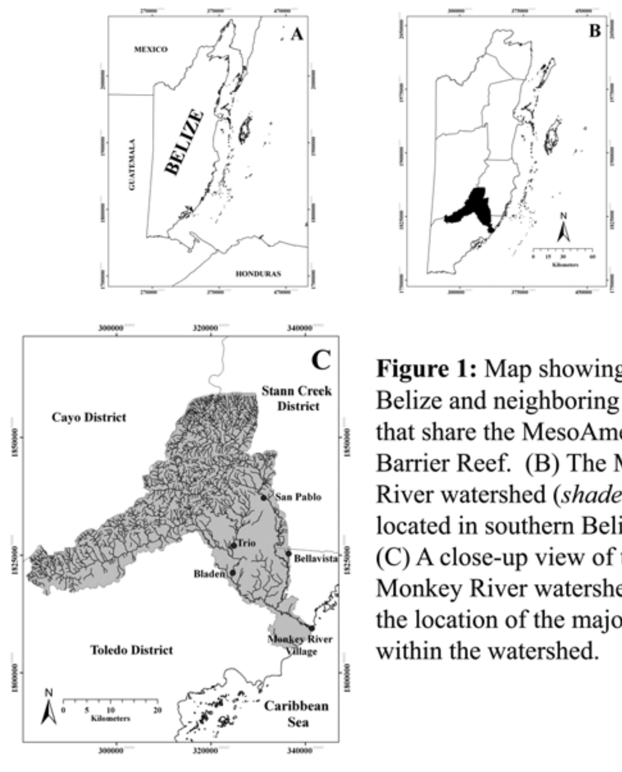

Figure 1: Map showing (A) Belize and neighboring countries that share the MesoAmerican Barrier Reef. (B) The Monkey River watershed (*shaded area*) is located in southern Belize. (C) A close-up view of the Monkey River watershed shows the location of the major villages within the watershed.

The headwaters of all three branches drain mountainous, primarily undisturbed tropical broadleaf forest. The middle reaches flow through human-dominated landscapes that include commercial banana cultivation, pasture, gravel mining, and subsistence agriculture. Human settlements are also concentrated within the middle reaches (Fig 1). The lower reaches, below the confluence of the Bladen and Swasey Branches, are largely undeveloped.

Methods

Field work was conducted in four separate excursions during March 2007. Based on previous human impact mapping methodologies, a seven-step process was used to convert the stress-source point data into stress-specific expected local stress intensity maps. The end products of this process are color-coded maps showing the intensity of stresses originating within 1 km segments of the river for the entire drainage. The methods followed in each step are detailed below.

Step 1. *Map stress-sources*. Stress-source data were collected along the main stems of the Bladen, Trio, Swasey, and Monkey Rivers (in kayaks and canoes). All human activities proximate to the main channel were marked using a Garmin 72 handheld GPS, classified into one of eighteen "stress-source classes" (Table 1). Raw data were mapped using Arc Info.

Table 1: Stress-source classes used to identify human activities along the banks of the Monkey River and its main tributaries.

Stress-Source Class	Description
Channelization	A place where the active stream channel has been diverted to a new, man-made channel.
Drainage Ditch	A point of discharge for artificial drainage channels originating in commercial banana or citrus fields.
In-stream Gravel Mining	An area where sand and gravel beds are being commercially mined and extracted as a source of building aggregate.
In-stream Grazing	An area of livestock access to the main river channel that shows evidence of impact (bank failure, puddling of substrate, manure).
Laundry	An area commonly used by local residents for laundry.
Pump house	A point along the channel where water is extracted for agricultural irrigation.
Road	A location where a road has been cut to the river or crosses the river.
Sandbag dam	A point in the channel where sandbags have been stacked to create a temporary impoundment across the stream to facilitate water pumping.
No riparian buffer-buildings/residential	An area where riparian buffer has been completely removed and human settlement is proximate to the river bank.
No riparian buffer-cattle grazing	An area where the riparian buffer has been completely removed and cattle grazing occurs in the floodplain.
No riparian buffer-commercial agriculture	An area where the riparian buffer has been completely removed and commercial agriculture occurs in the floodplain.
No riparian buffer-milpa	An area where the riparian buffer has been completely removed and milpa (slash-and-burn) agriculture is present.
No riparian buffer-old milpa	An area where the riparian buffer has been completely removed and abandoned milpa is present.
Thin Buffer-buildings/residential	An area of thin riparian buffer (< 10m) where human settlement is proximate to the river bank.
Thin Buffer-cattle grazing	An area of thin riparian buffer (< 10m) where cattle grazing occurs in the floodplain.
Thin Buffer-commercial agriculture	An area of thin riparian buffer (< 10m) where commercial agriculture occurs in the floodplain.
Thin Buffer-milpa	An area of thin riparian buffer (< 10m) where milpa agriculture occurs in the floodplain.
Thin Buffer-old milpa	An area of thin riparian buffer (< 10m) where abandoned milpa is present in the floodplain.

Step 2. *Identify stress/stress-source associations*. Each stress-source was linked to the corresponding stresses to which it contributes (Table 2). Linkages were based on a review of scientific literature and professional judgment (Table 3).

Table 2: Seven stress types were identified through an analysis of stress-sources documented during field work. Human-induced impacts to riparian zones alter the natural variability in freshwater ecosystems and can directly alter ecosystem structure and function.

Stress	Description
Sedimentation	Artificially high amounts of sediment in the stream channel from in-stream and external sources. "Chokes up" the streambed, alters habitat, and affects biota.
Nutrient loading	Elevated amounts of growth limiting nutrients (Nitrogen and Phosphorus) in the water beyond limits of natural variation. Alters food webs, creates algal blooms, and causes eutrophication.
Toxins/contaminants	Present of pesticides, herbicides, heavy metals, chlorine, petroleum products, and other artificial agents that harm living organisms.
Altered flow regime	The changing of natural patterns of flow to which freshwater and coastal organisms have adapted to survive. Caused by damming of rivers, changing drainage patterns (e.g., adding drainage ditches), excessive water pumping, and lowering of water table.
Thermal alteration	Water temperatures that have been changed to beyond the natural range of variation. Affects the metabolism, reproduction, and life cycles of many aquatic organisms.
Habitat fragmentation/alteration	Disconnection of portions of the stream channel from one another through channel obstructions such as dams. Migratory biota (e.g., mountain mullet) are often heavily impacted.

Step 3. *Rank sources*. For each stress, sources were ranked on a scale of "significance of contribution" (Very high, High, Medium, Low) using criteria established by The Nature Conservancy. Final ranks were determined by combining ranks from the following two factors (TNC 2000, page VI-2):

> Degree of contribution to the stress – The contribution of a source, acting alone to the full expression of a stress, assuming the continuation of the existing management/ conservation situation. Does (or did) the particular source make a very large or substantial contribution to causing the current stress, or a moderate or low contribution?
>
> Irreversibility – The reversibility of the stress caused by the source. Does (or did) the source produce a stress that is irreversible, reversible at extremely high cost, or reversible with moderate or little investment?"

Combining ranks from these factors (using a pre-established combining table; TNC 2000, page A-9) resulted in an overall source rank of Very High, High, Medium, or Low (Appendix 1). For the purpose of source intensity mapping, numeric values were assigned to each source rank (Very high=10, High=7.5, Medium=5, Low=2.5) to allow for addition of source scores in discrete river segments.

Step 4. *Segment river*. A map of the river was segmented into 1 km reaches in an upstream direction from the river mouth. Segments were reset at confluences with major tributaries (e.g., the Bladen and Swasey branch confluences with Monkey River), and each segment was converted into a polygon (hand drawn to align with segment boundaries, and then clipped by a

100 m buffer around the river), and labeled. These segment polygons became the basis for comparing source intensities.

Table 3: Stress-source relationships and the scientific literature used to justify these relationships. When no scientific literature was available, personal observation was used to justify relationships.

Stress	**Sources**	**References**
Sedimentation	No riparian buffer	Wood and Armitage 1997; Osborne and Kovacic 1993; Lowrance et al. 1997
	Drainage ditches	Usher and Pulver 1994
	In-stream gravel mining	Brown et al. 1998, Sandecki 1989
	Channelization	Brookes 1986
	Grazing	Metzeling et al. 1995; Owens et al. 1996
	Road access	Cline et al. 1982; Metzeling et al. 1995
	Thin buffer	Wood and Armitage 1997
Nutrient loading	Drainage ditches	Usher and Pulver 1994
	No riparian buffer	Osborne and Kovacic 1993; Peterjohn and Correll 1984; Lowrance et al. 1984
	Laundry/Community use	Quddus 1980
	Grazing	Line et al. 2000
	Thin riparian buffer	Lowrance et al. 1997
Toxins/Contaminants	Drainage ditches	Usher and Pulver 1994
	No riparian buffer	Usher and Pulver 1994; Lowrance et al. 1997; Nearly et al. 1993
	Thin buffer	Lowrance et al. 1997; Nearly et al. 1993
Altered flow regime	Drainage ditches	Poff et al. 1997
	Water pumping	Poff et al. 1997
	In-stream gravel mining	Mas-Pla et al. 1999
Thermal alteration	No riparian buffer	Osborne and Kovacic 1993; Gregory et al. 1991
	Drainage ditches	
Direct habitat alteration	No riparian buffer	Gregory et al. 1991; Harmon et al. 1986
	In-stream gravel mining	Brown et al. 1998; Sandecki 1989; Kondolf 1997
	Channelization	Brookes 1986
	Water pumping	

Step 5. *Tally source rank scores in each segment.* The segmented river map (from step 4) was overlain, on a stress-by-stress basis, with source point data from step 1. For example, for the stress "Altered flow regime", the points marking "drainage ditces", "water pumping", and "in-stream gravel mining" were displayed on the segmented map. Then, within each segment, source rank scores (from step 3, see Appendix 1) associated with these points were added and entered into a table to keep track of overall segment scores for each stress. Building on the example above, if segment BL001 had two drainage ditches in it (source rank score=2.5) and only one water pump- house (score=5) then the tally for BL001 would equal (2 DD x2.5)+(1 PH x5). Thus, 10 would be the *relative source intensity* for segment BL001.

Step 6. *Create source intensity maps*. At the completion of step 5, for each stress type, each segment had a source intensity score associated with it. Categorical break points were established by ranking all scores for a given source and dividing the rankings into quartiles. Each quartile therefore coincides with one of the four levels of significance. The lower quartile was classified as Low, the middle quartiles were classified as Medium and High and the upper quartile was classified as Very High. Each level was color coded for mapping: Very high (red), High (orange), Medium (yellow), and Low (bright green). Segments with no stress-sources were left colorless. In our example, if the score for segment BL001 fell in the low range, it would be colored bright green on the map.

Step 7. *Create "overall expected stress intensity" map*. It was informative at the end of the analysis to add segment scores of all stresses to create a map of overall expected stress intensities. The resulting scores identify stream segments expected to be experiencing the most intense combined stress. At the completion of this step, seven maps, one for each stress type, and one showing overall source intensity were generated.

Results

The observed human impacts in the Monkey River watershed vary across all three main branches. Impacts within the Bladen Branch (Fig 2.A) are dominated by milpa agriculture (including old and active milpa as well as thin buffered and no buffer). Milpa comprises ~65% of the observations in the Bladen. In contrast, impacts along the Trio Branch (Fig 2.B) are almost exclusively dominated by cattle grazing (~75%). This includes observations of grazing with a thin buffer, no buffer, and cattle access to the river channel. Observed impacts along the Swasey Branch (Figure 2.C) are more varied than the other branches of the Monkey River. In-stream gravel mining accounts for 9% of the observations while commercial agriculture (banana) and cattle grazing each account for 15% of the observations. The most observed impact in the Swasey Branch is from milpa agriculture (~40%). Below the confluence of the Bladen and Swasey branches, the riparian zone of the Monkey River is relatively unimpacted. A total of five observations were made between the confluence and Monkey River Village (Fig 2.D).

Expected Local Stress Intensity Index

A total of six primary stresses were identified in the Monkey River watershed (Table 3). Stress-source intensity maps were generated for each of these six stresses as well as an overall index map.

Sedimentation

The sedimentation stress-source intensity map (Fig 3) highlights areas along the Trio Branch as well as the Swasey Branch below San Pablo. The primary stress-sources for sedimentation in the Monkey River watershed are cattle grazing (Trio) and commercial agriculture (Swasey). In both cases, riparian forest zones are cleared directly up to the river's edge. This increases the potential for bank failure and limits the retention of sediment transport during periods of high flow.

Nutrient loading

The nutrient loading stress-source intensity map (Fig 4) highlights areas of very high impact along the Trio Branch as well as parts of the Bladen and Swasey Branches where there is no intact riparian buffer. In the Trio Branch, no (or very thin) riparian buffer allows for numerous locations where cattle can access the river. The potential for retention of nutrients moving across this pasture-dominated landscape is also greatly reduced because of the poor quality of riparian forests in the lower reaches of the Trio. Areas of high and very high impact in the Bladen and

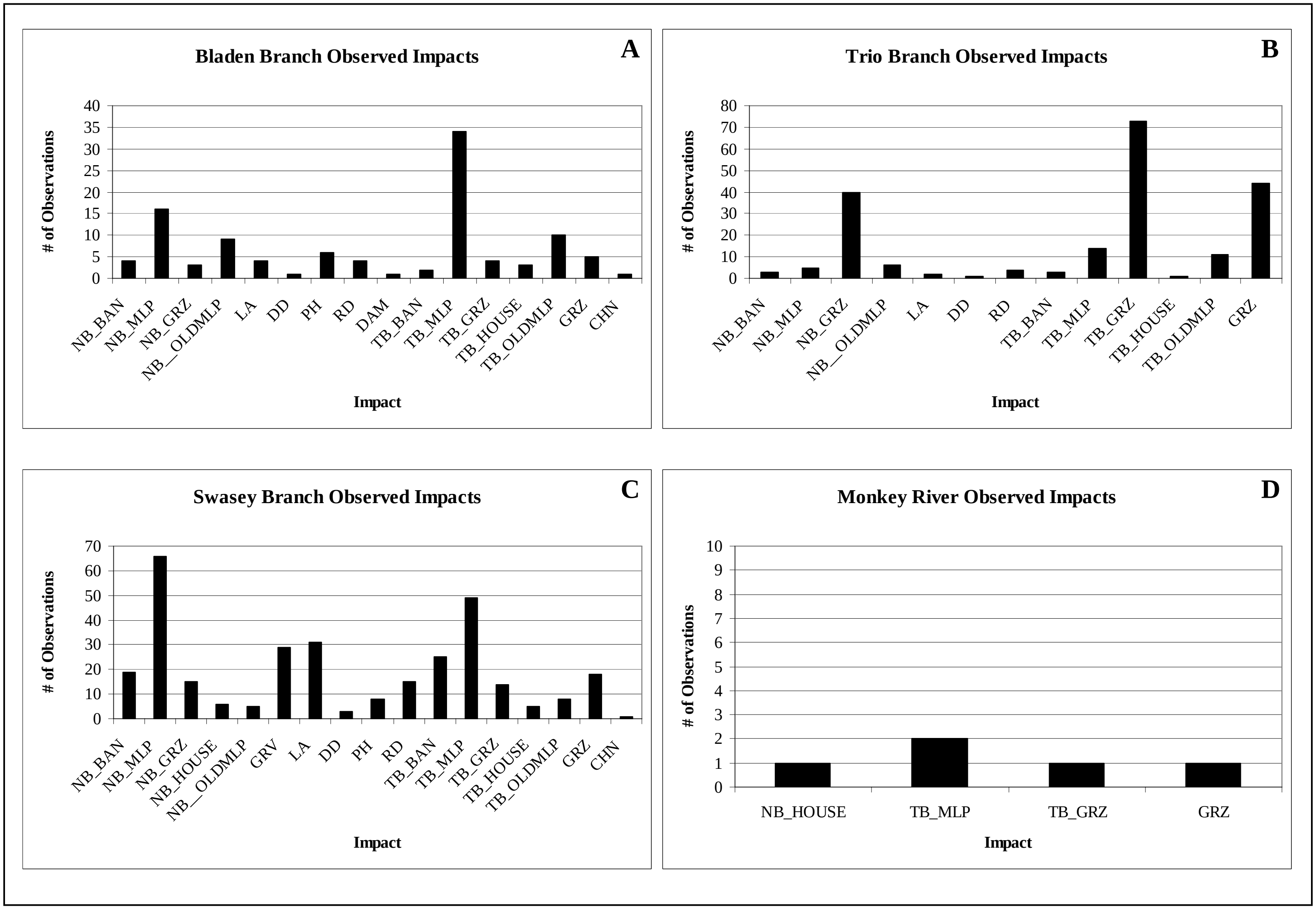

Figure 2: The observed sources of stress in each of the three branches of the Monkey River (Bladen Branch = A; Trio Branch = B; Swasey Branch = C) as well as the main stem of the Monkey River (D) below the confluence of the Bladen and Swasey branches. Very few observations were made along the Monkey River (D). (Note the differing 'y' axes). See Appendix 1 for code definitions.

Swasey Branches include areas where the potential for agricultural run-off is high (commercial banana) and human access points provide areas for laundry and the washing of agricultural equipment (e.g. backpack sprayers) that enters the river directly.

Toxics/Contaminants
The toxics/contaminants stress-source intensity map (Fig 5) highlights areas of thin or no buffer where land uses can introduce hazardous chemicals into the river. These include: commercial banana, milpa, and banana field drainage ditches (e.g. pesticides and fungicides), gravel mining (e.g. petroleum waste) as well as laundry areas and road crossings. The Swasey Branch contains the highest density of potential toxic/contaminant impacts while the reaches near the Bladen-Trio confluence also contain a lesser density of milpa and banana plantation activity.

Flow Alteration
Altered flow regimes in the Monkey River watershed occur from gravel mining activities, road crossings, irrigation pump houses and associated dam structures. The flow alteration stress-source intensity map (Fig 6) shows the highest density of these impacts along the Swasey Branch. Pump houses and drainage ditches contribute to the ELSI ranking along the Bladen and Trio Branches.

Habitat Alteration
Activities that alter the natural flow regime (see: *Flow Alteration*) also impact the distribution of naturally occurring habitat in the Monkey River watershed. Cattle access to the main river channel can severely impact aquatic habitats directly via trampling and modification of the substrate as well as indirectly via nutrient enrichment. Areas of ‘very high’ ELSI scores for habitat alteration in the Trio Branch (Fig 7) are almost exclusively the result of in-stream cattle pressure. Habitat alteration in the Swasey and lower Bladen Branches is a result of the above-mentioned land uses as well areas of thin or no riparian buffer.

Thermal Alteration
The thermal alteration stress-source intensity map (Fig 8) highlights areas of thin or no riparian buffer as well as areas where drainage ditches and pump houses alter the flow and consequently temperature regime of the river. Riparian buffers are most severely impacted along the Trio Branch while the Bladen and Swasey Branches experience thermal alterations from the broader range of potential impact sources.

Overall ELSI Score
Land use within the riparian zone and associated floodplains of the Monkey River watershed is diverse and the potential stresses on aquatic ecosystems are equally as diverse (see Table 1). The overall ELSI score map (Fig 9) reflects this diversity of human impacts within the riparian zone of the watershed. The dominant land uses in the watershed (commercial agriculture, grazing and milpa) severely impact riparian zone forests while additional pressures from gravel mining and general human use (e.g. laundry) further impact aquatic ecosystem health in the watershed.

Conclusions/Recommendations
Effective conservation of aquatic resources within the Maya Mountain Marine Corridor (MMMC) and the greater Port Honduras watershed requires an integrated management strategy that incorporates human activities occurring at the terrestrial-aquatic interface. Human impact mapping provides a spatially explicit method for identifying human activities within the riparian zone. It allows researchers and conservation practitioners to predict the severity and scope of

stresses based on assumed relationships between sources and the stresses to which they contribute.

In the Monkey River watershed, human impact mapping has identified river segments that require mitigation in order to alleviate further stresses to the watershed's aquatic resources. The Bladen Branch of the Monkey River experiences a broad range of impacts with the most dominant impact being milpa agriculture. Farmers clear and burn forests up to the river's edge and severely reduce riparian forest function. Additional human activities are often associated with milpa agriculture (e.g. irrigation, pesticide use) and further accentuate the impact of this land use on aquatic ecosystems. Pasture expansion in the Trio Branch has severely compromised the middle and lower reaches of the watershed. In addition to the above-mentioned impacts stemming from cattle, pasture development along the Trio Branch also includes significant numbers of barbed-wire fences stretched across the main channel. This not only represents a significant recreational hazard but also encourages large snags and impedes the natural flow of the river. The Swasey Branch experiences a broad range of impacts including commercial banana, milpa, gravel mining, grazing, and laundry areas. The interaction between all of these impacts results in the 'high' to 'very high' ELSI rankings through much of the lower Swasey Branch. Mitigation of these stresses requires collaborative efforts between local land owners and conservation organizations.

Specific recommendations for TIDE's conservation attention include:

1. Trio Branch is a high priority for mitigation of stresses associated with cattle ranching. TIDE should hold community consultations, educate land owners about national laws protecting riparian forests, and initiate riparian restoration efforts similar to those conducted in the Rio Grande watershed. Addressing this issue with Trio Village cattle ranchers would also help to improve conditions on the Bladen Branch above Trio confluence.

2. Swasey Branch historically has had the most persistent, most intense, and most diverse mix of threats to aquatic ecosystems. Based on personal observation, land use practices in the banana farms have improved, with fewer incursions into the riparian zone, and fewer drains that run directly to the main river channel. However, no buffer and thin buffer points were very high, and thus TIDE's attention to riparian forest protection, rehabilitation, and restoration are very warranted. A Spanish language educational campaign could be effective, and focused attention on outreach to land owners in the upper Swasey between San Pablo and the S. Highway Bridge are well-justified.

3. Research into severity of toxics buildup in Swasey Branch and Bladen Branch below the Trio confluence could give TIDE a strong lever with which to influence human communities living in the banana farming areas—these same communities are at risk from these chemicals. Solid information that implicated the banana industry could also help gain the cooperation of the Banana Growers Association or specific farm owners. This is undoubtedly an issue that has long-term potential (e.g., 30 years) to influence ecosystems and human communities into the future. The new water quality lab being set up at University of Belize could provide the facilities necessary to undertake such studies.

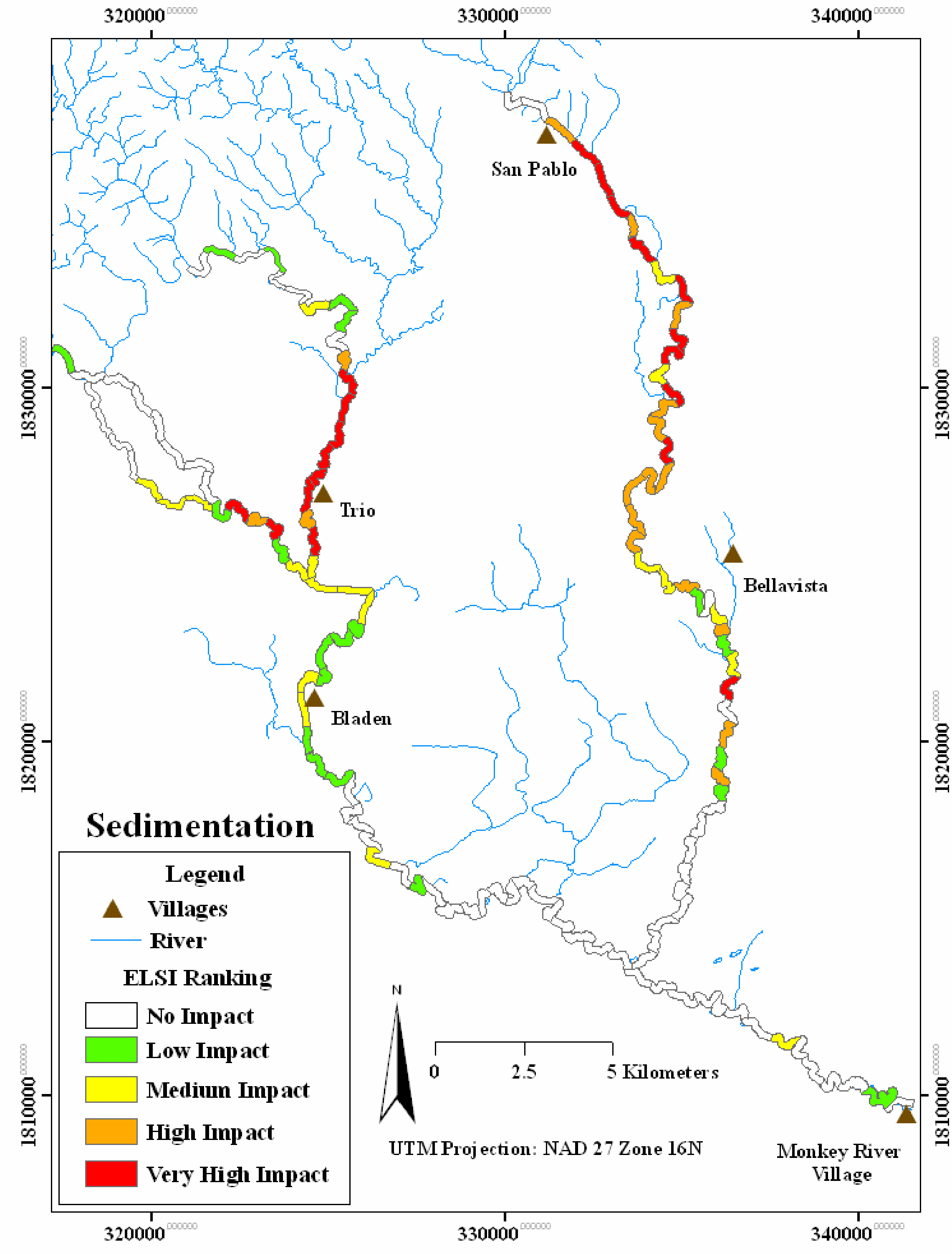

Figure 3: 'Sedimentation' stress-source intensity map for the Monkey River watershed and its main tributaries.

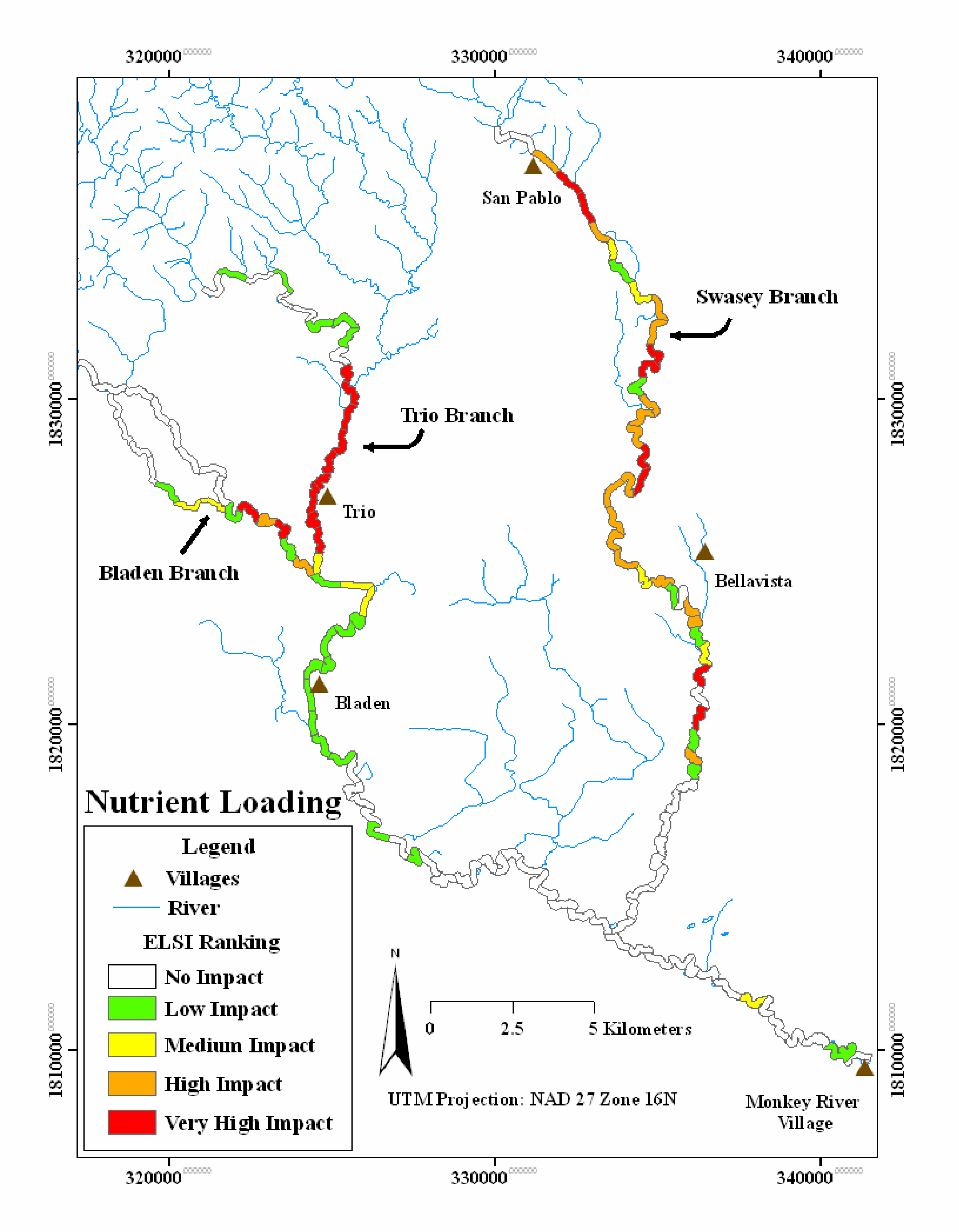

Figure 4: 'Nutrient loading' stress-source intensity map for Monkey River watershed and its main tributaries.

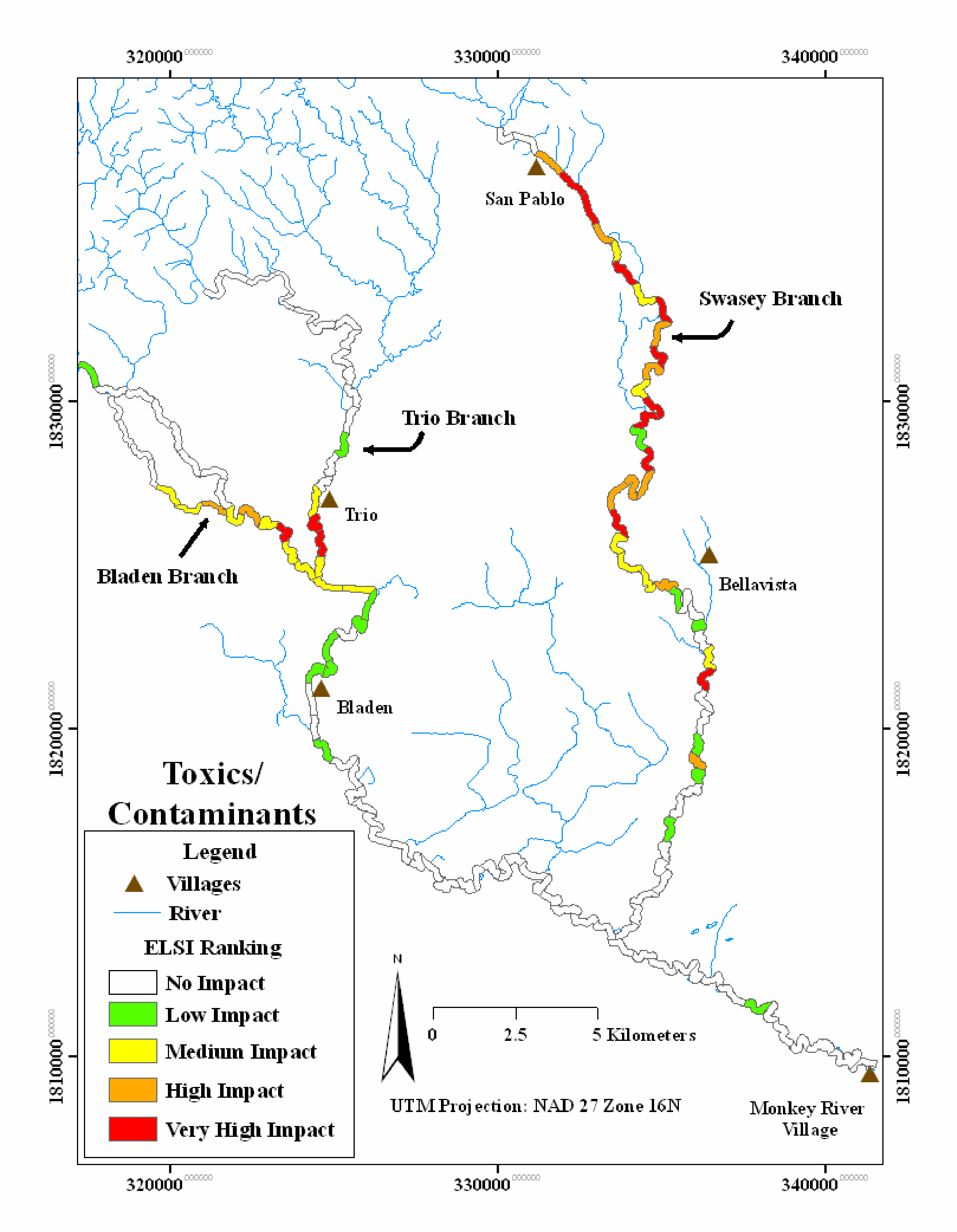

Figure 5: 'Toxics/contaminants' stress-source intensity map for the Monkey River watershed and its main tributaries.

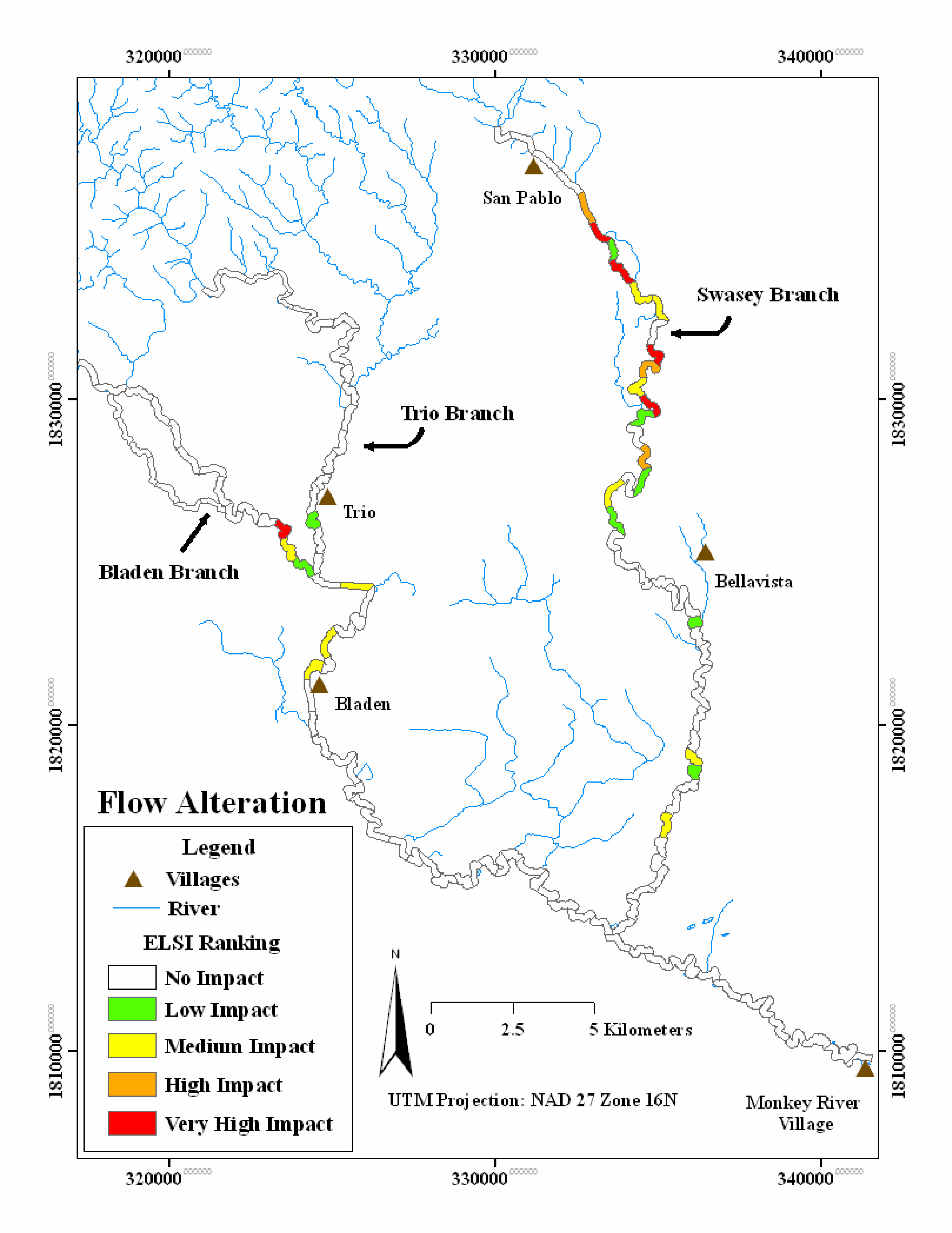

Figure 6: 'Flow alteration' stress-source intensity map for the Monkey River watershed and its main tributaries.

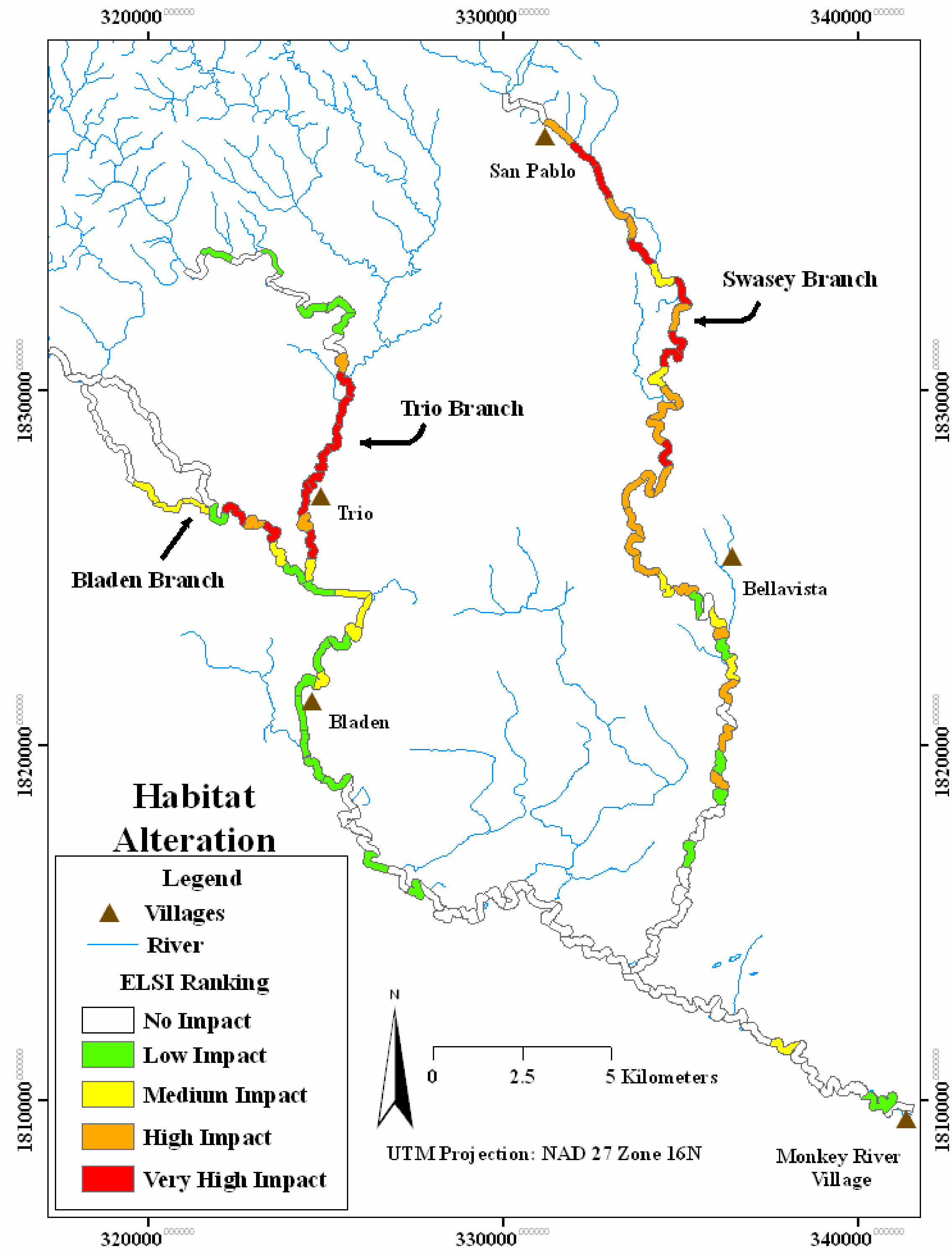

Figure 7: 'Habitat alteration' stress-source intensity map for the Monkey River watershed and its main tributaries.

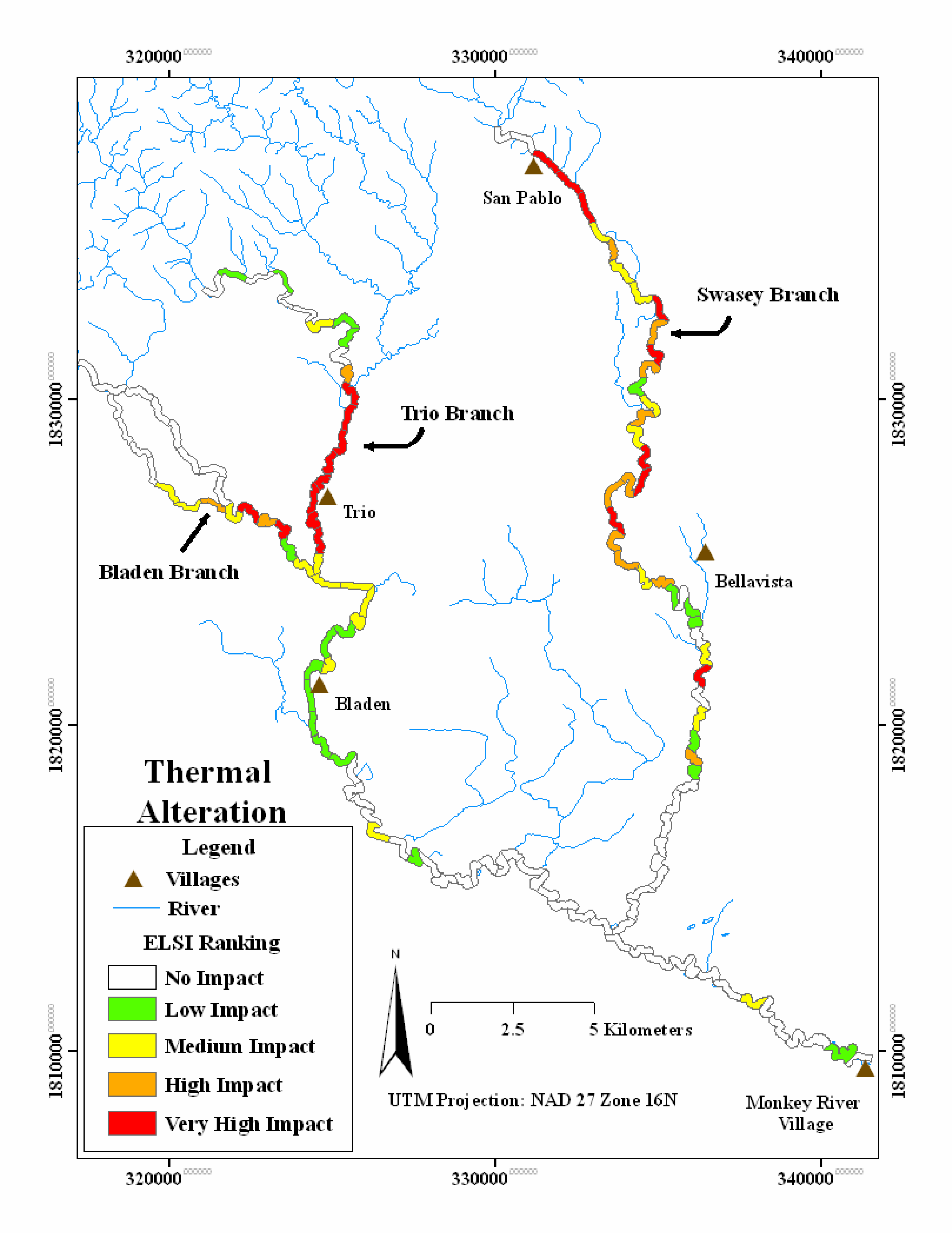

Figure8: 'Thermal Alteration' stress-source intensity map for the Monkey River watershed and its main tributaries.

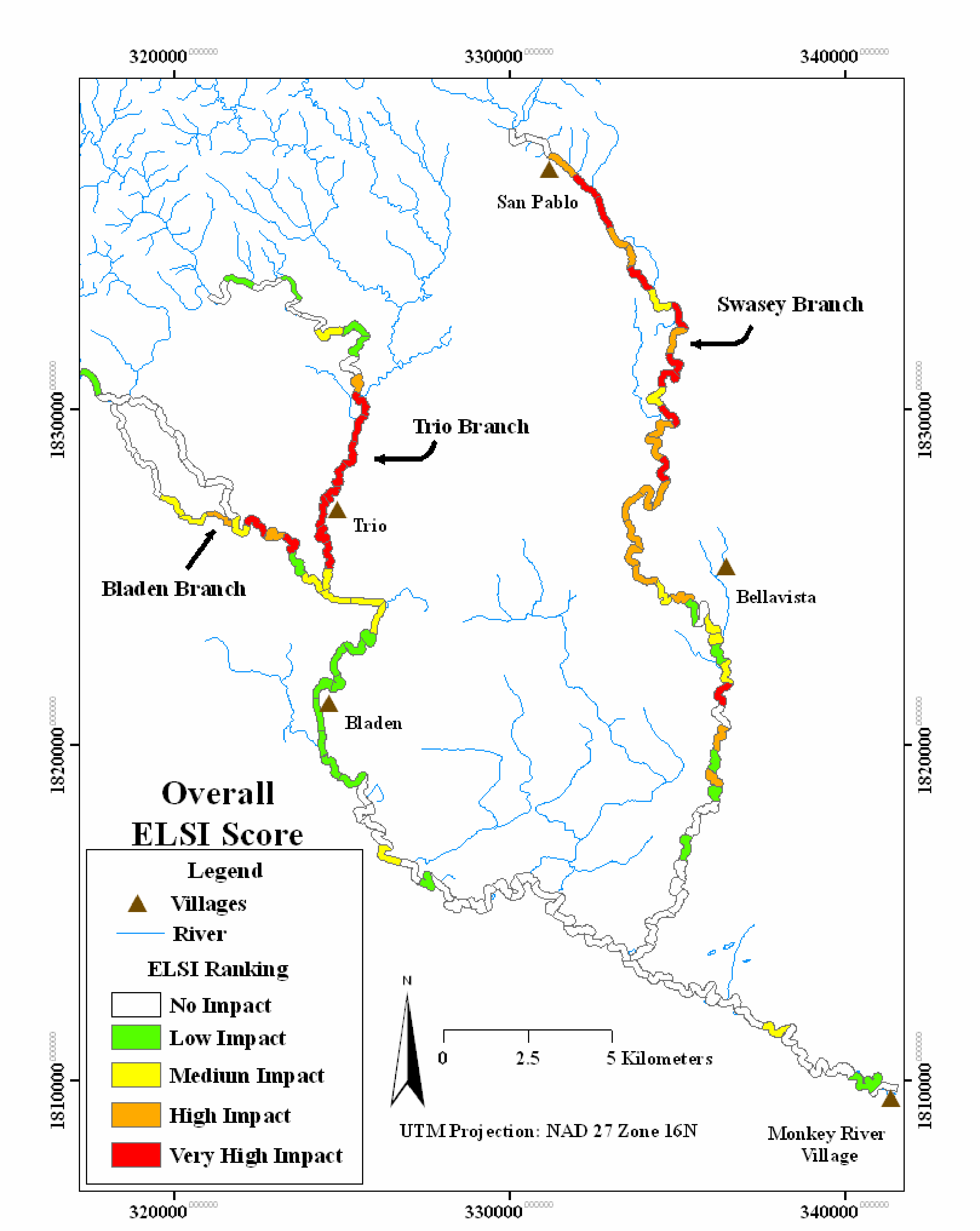

Figure 9: 'Overall ELSI Score' map for the Monkey RIver watershed and its main tributaries.

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Appendix 1: Table showing the rankings assigned to stresses, stress-sources and the ultimate score assigned to all observed human impacts in the Monkey River watershed.

Stress	Sources	Source Code	Contrib.	Irrevers.	Rank	Rank Score
Sedimentation	No riparian buffer-commercial agriculture	NB (BAN)	H	H	H	10
	No riparian buffer-milpa	NB (MLP)	M	H	M	5
	No riparian buffer-old milpa	NB (OLDMLP)	L	H	M	5
	No riparian buffer-cattle grazing	NB (GRZ)	H	H	H	7.5
	No riparian buffer-buildings/residential	NB (house)	L	H	M	5
	Thin Buffer-commercial agriculture	TB (BAN)	M	H	M	5
	Thin Buffer-milpa	TB (MLP)	L	H	M	5
	Thin Buffer-old milpa	TB (OLDMLP)	L	H	M	5
	Thin Buffer-cattle grazing	TB (GRZ)	H	H	H	7.5
	Thin Buffer-buildings/residential	TB (house)	L	H	M	5
	In-stream gravel mining	GRV	V	H	V	10
	Channelization	CHN	H	H	H	7.5
	In-stream Grazing	GRZ	V	H	V	10
	Road access	RD	H	H	H	7.5
	Drainage ditch	DD	M	H	M	5
Nutrient loading	No riparian buffer-commercial agriculture	NB (BAN)	H	M	M	5
	No riparian buffer-milpa	NB (MLP)	L	M	L	2.5
	No riparian buffer-old milpa	NB (OLDMLP)	L	M	L	2.5
	No riparian buffer-cattle grazing	NB (GRZ)	H	M	M	5
	No riparian buffer-buildings/residential	NB (house)	L	M	L	2.5
	Thin Buffer-commercial agriculture	TB (BAN)	M	M	M	5
	Thin Buffer-milpa	TB (MLP)	L	M	L	2.5
	Thin Buffer-old milpa	TB (OLDMLP)	L	M	L	2.5
	Thin Buffer-cattle grazing	TB (GRZ)	M	M	M	5
	Thin Buffer-buildings/residential	TB (house)	L	M	L	2.5
	Laundry	CU	L	M	L	2.5
	In-stream Grazing	GRZ	H	M	M	5
	Drainage ditches	DD	V	M	H	7.5
Toxins/Contaminants	No riparian buffer-commercial agriculture	NB (BAN)	H	H	H	7.5
	No riparian buffer-milpa	NB (MLP)	M	H	M	5
	In-stream gravel mining	GR	L	H	M	5
	Thin Buffer-commercial agriculture	TB (BAN)	M	H	M	5
	Thin Buffer-milpa	TB (MLP)	L	H	M	5
	Pump house	PH	L	H	M	5
	Road access	RD	L	H	M	5
	Drainage ditches	DD	V	H	V	10
Altered flow regime	Water pumping	PH	M	M	M	5
	In stream gravel mining	GRA	L	M	L	2.5
	Drainage ditches	DD	L	M	L	2.5
Habitat alteration/ fragmentation	No riparian buffer-commercial agriculture	NB (BAN)	M	M	M	5
	No riparian buffer-milpa	NB (MLP)	M	M	M	5
	No riparian buffer-old milpa	NB (OLDMLP)	M	M	M	5
	No riparian buffer-cattle grazing	NB (GRZ)	M	M	M	5

	No riparian buffer-buildings/residential	NB (house)	M	M	M	5
	Thin Buffer-commercial agriculture	TB (BAN)	L	M	L	2.5
	Thin Buffer-milpa	TB (MLP)	L	M	L	2.5
	Thin Buffer-old milpa	TB (OLDMLP)	L	M	L	2.5
	Thin Buffer-cattle grazing	TB (GRZ)	L	M	L	2.5
	Thin Buffer-buildings/residential	TB (house)	L	M	L	2.5
	In-stream gravel mining	GR	H	M	M	5
	In-stream Grazing	GRZ	M	M	M	5
	Channelization	CHN	L	M	L	2.5
	Pump house	PH	L	M	L	2.5
	Sandbag dam	DAM	L	L	L	2.5
	Gravel mining	GRV	L	L	L	2.5
Thermal alteration	No riparian buffer-commercial agriculture	NB (BAN)	H	M	M	5
	No riparian buffer-milpa	NB (MLP)	H	M	M	5
	No riparian buffer-old milpa	NB (OLDMLP)	H	M	M	5
	No riparian buffer-cattle grazing	NB (GRZ)	H	M	M	5
	No riparian buffer-buildings/residential	NB (house)	H	M	M	5
	Drainage ditches	DD	L	M	M	5
	Thin Buffer-commercial agriculture	TB (BAN)	L	M	M	5
	Thin Buffer-milpa	TB (MLP)	L	M	M	5
	Thin Buffer-old milpa	TB (OLDMLP)	L	M	M	5
	Thin Buffer-cattle grazing	TB (GRZ)	L	M	M	5
	Thin Buffer-buildings/residential	TB (house)	L	M	M	5