

EY

# **Impact of Ecohydrological Changes from Human Influences on Global Public Health**

---

**Laura M. Suppes**

**Abstract:**

*Both global climate and landscapes have changed due to anthropogenic activity, which is having a profound effect on regional ecological and hydrological processes. The interdisciplinary study of both ecology and hydrology is termed ecohydrology. Precipitation pattern and land use changes, specifically, have altered natural vegetative states and runoff rates, increasing the likelihood of flooding. Flood waters provide a reservoir and a transport mechanism for pathogens, which can cause disease in exposed populations. The relationship between ecohydrological processes and waterborne disease is important to consider when assessing the health of populations that have experienced a flooding event. Research and information exist in ecology, hydrology and public health that emphasize each field's contribution and relationship to flooding. However, no synthesis exists explaining the linkages between ecohydrology and public health. One important linkage between the two fields is flooding. The following synthesis recognizes; 1) the ecohydrological factors that increase and decrease the severity and likelihood of flooding; and 2) the public health implications of flooding. The objective of this synthesis is to recognize what ecohydrological factors influence flooding in order to identify and recommend effective management practices that can reduce the impact of flooding on global public health.*

## **I. Introduction**

Anthropogenic influences on the environment are interfering with ecosystem dynamics throughout the world. The dynamic of an ecosystem involves all environmental aspects, including land, elements, and living creatures. Interactions between global ecosystem functions can induce harmful feedback effects within ecosystem dynamics. The four functions of the global ecosystem according to the Millennium Ecosystem Assessment (MEA 2005a) include: biodiversity, human well-being, indirect drivers of change and direct drivers of change.

Alterations in Indirect drivers of change, like population growth, can affect direct drivers, such as global climate and land use. The MEA specifically identifies the need to address climate and land use alterations in arid and semiarid ecosystems because these areas host two-thirds of the global population and are very sensitive to change (MEA 2005b). Human population growth and urbanization have impacted climate patterns and land use activities, which in turn have impacted population health.

Two of the most prominent direct changes induced by population growth have been global precipitation patterns (climate change), and ecosystem state transitions (land use). Feedbacks between precipitation patterns and ecosystem states can be analyzed by assessing both the ecology (vegetation, soil organisms, soil properties, etc.) and hydrologic inputs and outputs (precipitation, groundwater recharge, etc.) of an area. This scientific approach is known as ecohydrology. Ecohydrology is an emerging field that combines the studies of ecology and hydrology, and is used to assess system feedbacks (Newman et al. 2006). Knowledge of the

feedbacks between increased precipitation rates and degraded ecosystems is important for maintaining public health because areas experiencing these changes are subject to a greater risk of flooding, which can impact water quality and increase the incidence of disease. Ecology, hydrology and public health are interrelated. Relationships exist between each field and flooding, however, there is currently no existing synthesis that explains these relationships. The objective of this synthesis is to identify the feedbacks and interactions between land use degradation, increased precipitation rates, and incidence of waterborne diseases, in an attempt to answer how ecohydrological changes from human influences are affecting flooding and global public health. In addition, effective management practices that can reduce the impact of flooding on global public health are recommended in the conclusion of this synthesis.

## **II. Approach**

A literature review in the fields of hydrology, ecology, ecohydrology and public health was performed in an attempt to recognize what ecohydrological factors influence flooding in order to identify effective management practices that can reduce the impact of flooding on global public health. The discussion section reviews the appropriate literature in each field. The four focus areas of the discussion include: vegetation influence on runoff, vegetation influence on river flow, flooding, and the public health implications of flooding. The results section identifies relationships between the four focus areas. Last, the conclusion suggests effective ecohydrological management practices that can reduce flooding based on the relationships identified in the results section.

### **III. Discussion**

#### **i. Vegetation Influence on Runoff**

Vegetation is an influential component of the water budget. Water from rainfall that contacts the land surface can have various fates, including; groundwater recharge, soil saturation, surface water recharge, runoff/over land flow, and uptake by vegetation. The most influential components of a landscape on rainfall partitioning are the soil structure and vegetation type/amount (Tongway et al. 2001). During intense precipitation events, the probability increases that a greater amount of water will be partitioned as runoff, as soil may become completely saturated and prohibit water infiltration; specifically after the soil's infiltration rate falls below rainfall intensity (Tongway et al. 2001). However, runoff decreases when vegetation is present because vegetation utilizes excess water from intense precipitation events (Scanlon et al. 2005). A study conducted by Ludwig et al. (2005) explains the impact of banded vegetation on soil infiltration after intense precipitation events. The study results indicate that the amount of soil wetness under vegetated areas after rainfall is significantly higher than intergrove areas without vegetation present. Figure 1 from Ludwig et al. shows the relationship between soil water availability and vegetation presence.

Similarly, Tongway et al. (2001) synthesized several studies showing that infiltration increases where vegetation bands are present, and decreases at interband areas. Tongway et al. also explain that rates of flooding increase in bare soil areas compared to catchment areas where vegetation is present (a chenopod shrubland-grassland community was specifically observed in

the referenced study). Table 1, taken from Tongway et al., shows data collected from a study comparing flooding and runoff coefficients (total volume of runoff/total volume of rainfall) in vegetated catchment versus bare soil regions. The data of the study illustrates that flood events over bare soils exceeded flood events over vegetated catchment areas during the rainy season of the study region.

In areas where bare soil dominates the landscape and where no vegetation is present to utilize excess water, intense precipitation events will result in increased runoff and overland flow. The transition from vegetated land to bare land has occurred in urbanized, agricultural, and over-grazed areas, which are consequently the areas most associated with, and affected by, flooding.

## **ii. Vegetation Influence on River Flow**

Extensive research exists supporting the positive influence that vegetation has on maintaining riverbanks. Bare riverbanks without vegetation erode faster than banks with vegetation.

Vegetation utilizes excess water from runoff and intense precipitation, which are primary contributors to river overflow and flooding. In Australia, researchers Brooks et al. (2002) compared two rivers with historically similar morphologies and contrasting human impact records. According to the researchers, the Thurra River was in the same state in 2002 as it was when the first Europeans settled in Australia 150 years prior. The Cann River, in comparison, experienced considerable degradation from human activity in the same time frame. When compared, the Cann River showed significant increases in channel slope, capacity and depth.

Brooks et al. attribute the greater channel erosion observed on the Cann River compared to the Thurra River to the lack of bank vegetation that resulted from human degradation and land use.

Similar results are described in other studies that analyze riverbank vegetation influence on erosion. Smith (1976) provides a compelling figure (Figure 2) illustrating a linear relationship between erosion rate and bank vegetation presence. As the percentage of roots from riverbank vegetation increases, the rate of erosion decreases. Millar (2000) describes similar conclusions. Figure 3 below from Millar provides an aerial view of the bank erosion that resulted from logging at the study site. One image was taken in 1940 before the riverbank was logged (a). The other image (b) was taken post-logging in 1993 of the same river and portion of the river. The figure provides visual evidence of the erosion that occurs when riverbank vegetation is degraded or removed.

Vegetation stabilizes riverbanks where present, indicating a relationship between root presence and soil erosion. Erosion occurs on riverbanks where bare soil exists in the same method described above on non-banded, bare soil surfaces. In banded and vegetated areas, however, plants take in excess water where present. Intense precipitation events will increase runoff in non-vegetative areas, which can raise river water loads. If a river lacks vegetation and experiences an influx of water in excess, a greater amount of water will be present for potential overflow and flooding.

### iii. Flooding

Rivers are reservoirs for runoff. As runoff rates increase due to lacking vegetation and decreased infiltration ability of bare soils, rivers can become overwhelmed. When rivers experience a large influx of runoff from an intense precipitation event and have degraded, non-vegetated banks, river overflow and flooding can occur. Degradation of riverbanks can be especially detrimental in arid and semiarid regions because bank recovery can take decades (Friedman et al. 1996). The slow recovery of riverbanks following a flooding event is of particular concern in arid/semi arid ecosystems because they represent 45 percent of the Earth's land surface (Food and Agricultural Association 2008).

The flow intensity of river water can be an essential part of flood-prediction. Water can have an accelerated or decelerated flow depending on the conditions of the environment and river. A function of flow commonly used in hydrology is termed the "Manning coefficient". The specific flow functions that the Manning coefficient addresses are channel velocity, flow area and channel slope (United States Environmental Protection Agency 2002). The Manning coefficient can be used to assess channel roughness, which is an indicator of the amount of vegetation present in a river (greater vegetation indicates greater roughness). Doncker et al. (2009) use the Manning coefficient to assess the influence of vegetation on flow. The study shows a high Manning coefficient with a large amount of biomass. A high Manning coefficient indicates a lower flow velocity. Doncker et al. show (Figure 4) that the Manning coefficient increases as biomass increases (decreased flow with more vegetation).

The Manning coefficient is also used by Anderson et al. (2006) to determine the effect of vegetation on flooding, specifically. The study focuses on the influences biomass density and heights can have on the Manning coefficient. The intensity of flood water flow was significantly reduced (a higher Manning coefficient observed) when there was greater biomass along riverbanks, especially in smaller-magnitude flooding. Vegetation height influenced larger floods only, as more water caused shorter vegetation to become submerged and therefore less influential. The researchers concluded that flood water flow is sensitive to biomass, and that flow sensitivity varies with flood magnitude.

Both the amount of vegetation and impervious surfaces in urbanized areas have changed as global populations have increased. According to Kundzewicz et al. (2010), vegetation has been removed, and more pavement, yards, roofs, roads etc. have been established in urban areas, decreasing infiltration rates and increasing runoff amounts. Additionally, more people have established communities in floodplains near rivers. A rise in the global population has also induced global climate change, which affects global precipitation and the incidence of flooding. There has been a global temperature increase of  $0.65^{\circ}\text{C}$  in the past 50 years. Kundzewicz and colleagues estimate that a global temperature increase of  $4^{\circ}\text{C}$  raises the number of people affected by flooding by 2.5 times that of a  $2^{\circ}\text{C}$  temperature increase. The combination of lost infiltration ability from more impervious surfaces and vegetation removal, the establishment of communities in floodplains, and an increase of global temperature and precipitation rates poses an increased risk of detrimental flooding events that have the potential to severely impact population health.

#### **iv. Public Health Implications of Flooding**

Disease outbreaks in populations exposed to flood waters is a public health concern. Pathogens can be transported in flood waters after overflow from saturated soils and rivers mixes with industrial, human and animal wastes, and enters the drinking water systems (particularly unprotected wells and surface water sources) (Colindres et al. 2007). A study of disease incidence following major flooding in Bangladesh (1988) revealed a significant impact on population health from waterborne disease-induced diarrhea (Siddique et al. 1991). Bangladesh is susceptible to flooding because it is an alluvial plain delta formed by the merging of the Ganges, Jamuna and Meghna rivers. In the 1988 Bangladesh flood, researchers observed diarrheal diseases (water and mucoid) to be the most common ailment of the flood-affected study population (diarrhea is a common symptom of waterborne pathogen infection) (Siddique et al. 1991). Table 2 below shows the illness rates and types observed in the study population.

Diarrhea is a common outcome of waterborne pathogen infection, and can cause severe dehydration resulting in death in exposed populations. Another study by Qadri and colleagues (2004) following a flood event in Bangladesh observed an increased incidence of diarrhea in the study population. The cause of diarrhea was from *Escherichia coli* and *Vibrio cholera*, two pathogens that can cause severe morbidity and mortality in infected persons.

Extensive research exists relating the incidence of waterborne disease outbreaks to flooding events. Other studies that have observed flood-induced illness outbreaks are listed in Table 3

below. The majority of available literature related to flooding and infectious disease focuses on developing countries because the health implications are greater in areas with less infrastructure and resources to prevent and resolve flooding events. It is especially important to consider developing countries that are arid or semiarid, as the recovery from flood degradation in these regions can be lengthy. Arid and semiarid regions have less vegetation densities and therefore less soil and riverbank stability. Climate change resulting in increased precipitation rates, intensities and flooding could affect the ecohydrology and population health of arid/semiarid developing countries.

#### **IV. Results**

The ecological, hydrological, ecohydrological and public health literature reviewed shows each field's relationship to flooding. Bare soil landscapes where vegetation has been removed increases the rate of runoff into rivers. Degraded riverbanks that lack vegetation affect runoff containment. Greater amounts of precipitation can overwhelm bare-banked rivers, which increases the severity and likelihood of flooding. Flood water acts as a reservoir and transport mechanism for pathogens that cause disease in exposed populations.

Urban populations are threatened by flooding because they are often established on floodplains and have less vegetation and more non-porous, man-made surfaces. The urban populations that are most vulnerable to flooding occupy arid/semiarid developing countries, where there is a greater sensitivity to change and lack of infrastructure. Flooding can induce waterborne disease outbreaks that impact public health.

The relationship between ecohydrology and public health can be viewed in Figure 5.

Ecohydrological processes are impacted by land use and climate change, affecting vegetation type and presence. Changes in vegetation may increase runoff and induce flooding. The water from a flood can host and transport pathogens that impact population health.

## **V. Conclusion**

Synthesizing research on flooding from ecohydrology and public health supports the hypothesis that there is a relationship between the two fields. Increased precipitation and land use from humans impacts runoff and flooding events (Figure 5). The four functions of the global ecosystem (biodiversity, human well-being, indirect drivers of change and direct drivers of change) have been altered and indirect drivers of change have influenced direct drivers. These alterations have changed the feedbacks between ecology and hydrology. Urban development, agriculture and over-grazing has decreased natural vegetation and the land's ability to infiltrate water. Less infiltration has led to increased runoff and flooding events, which can lead to disease outbreaks.

Based on the relationships identified in this synthesis between ecohydrology and public health, there are several management practices that can be applied to mitigate the impact flooding has on population health. The following recommended management practices aim to reduce the impacts that can lead to flooding when alterations in ecohydrological processes occur:

- 1) Maintain native vegetation to decrease runoff
  - a. Use land designated only for agriculture and grazing
  - b. Restore areas where vegetation has been removed from grazing and agriculture uses (ideally with native species)
  - c. Minimize urban expansion, or reduce the impact of urbanization by installing porous surfaces, and planting vegetation in both residential and commercial areas
- 2) Maintain riverbank vegetation to decrease flow velocity and excess water
  - a. Avoid logging trees near or on riverbanks
  - b. Restore riverbank vegetation where removed
- 3) Address increasing rates of intense precipitation events
  - a. Policy
    - i. Continued implementation of regulations aimed to decrease greenhouse gas emissions and climate change
  - b. Personal
    - i. Reduce personal greenhouse gas emissions

The mitigation recommendations target global, regional, local and personal audiences. In order to reduce flooding, anthropogenic impacts must be lessened. Human land use and activities driving climate change specifically need addressing. Reducing anthropogenic impacts on ecosystem will decrease the negative interactions between direct and indirect drivers of change, and improve ecosystem dynamics. Improving the ecosystem will lessen ecohydrological

process degradation and the incidence of flooding, therefore improving population health worldwide.

**Figures and Tables:**

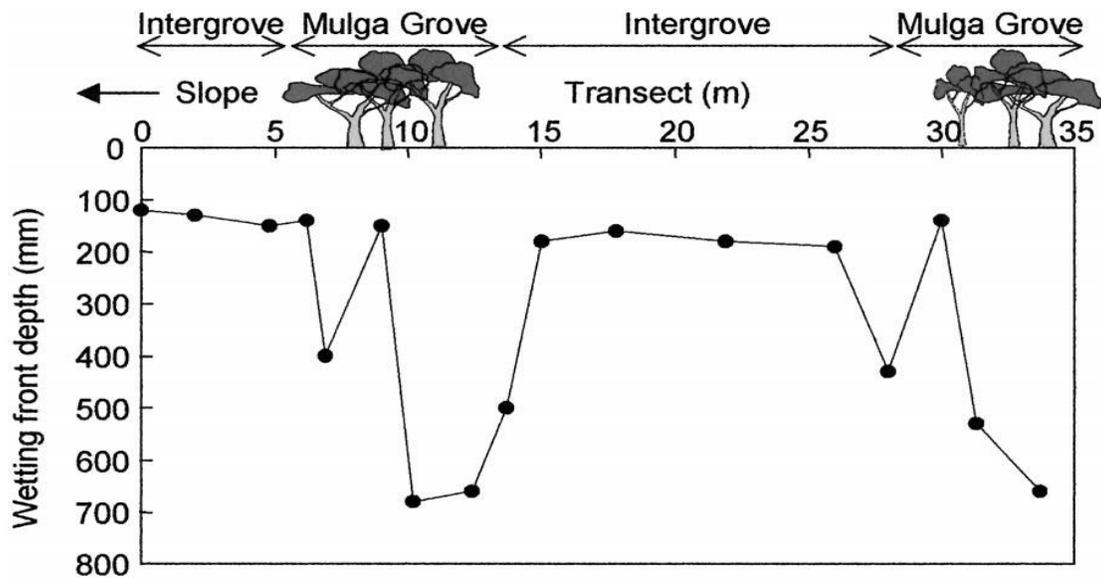


Figure 1 from Ludwig et al. (2005) illustrates the relationship between vegetation presence and soil-water availability. The soil under vegetation bands is significantly wetter compared to the intergrove area where no vegetation is present.

Table 1 from Tonway et al. (2001) shows an increase in the number of floods observed on bare soil versus a vegetated catchment area during intense precipitation events. The runoff coefficient is equal to the total volume of runoff/total volume of rainfall. A higher coefficient corresponds to a higher amount of runoff.

	Catchment 1993	Catchment 1994	Runoff Plot 1993	Runoff plot 1994
Date	7/30 8/13	7/21	7/29	7/21
Number of floods	21	25	27	29
Runoff coefficient	30.3	44.1	45	47

mean

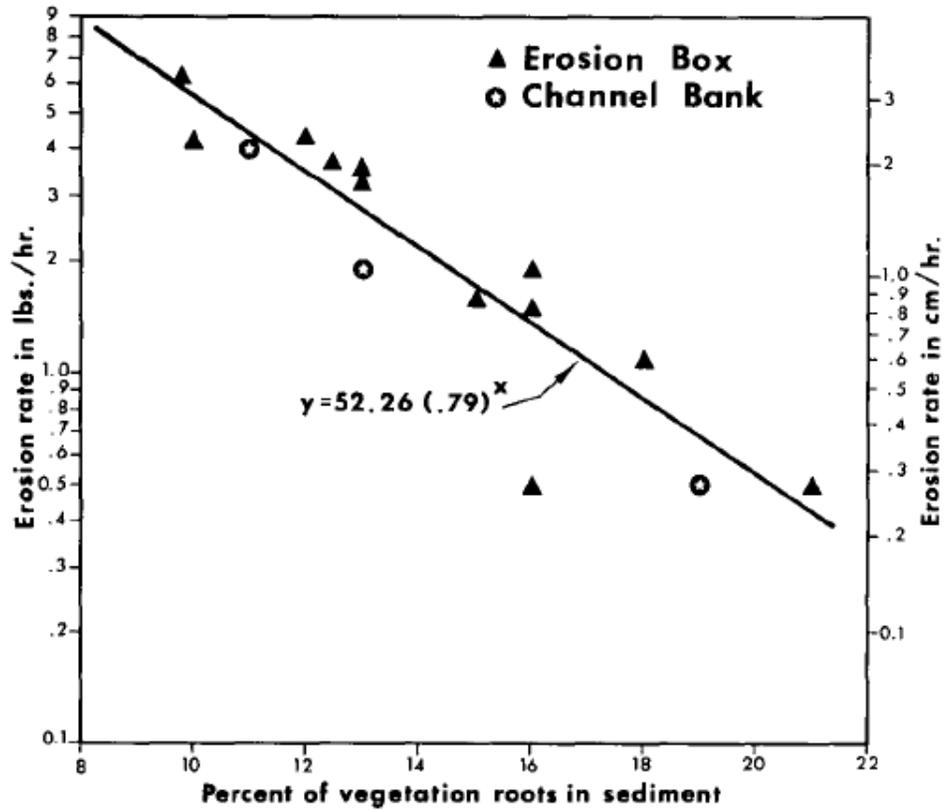


Figure 2 from Smith (1976) shows a decreasing erosion rate with an increase in the amount of vegetation present on riverbanks

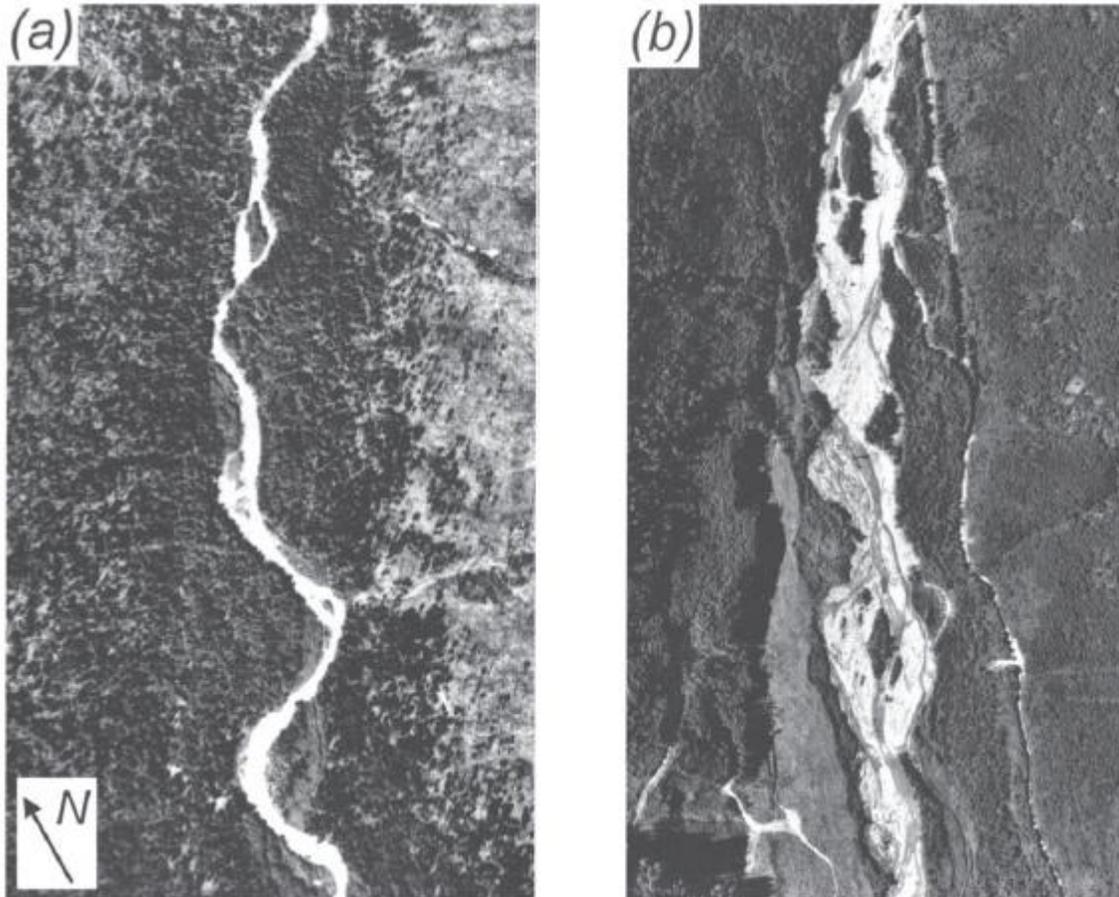


Figure 3 from Millar et al. (2000) compares two aerial photographs taken of the same river (and portion) at different times. Image a. was taken pre-logging in 1940, and image b. was taken post-logging in 1993. The images illustrate the impact of riverbank vegetation loss.

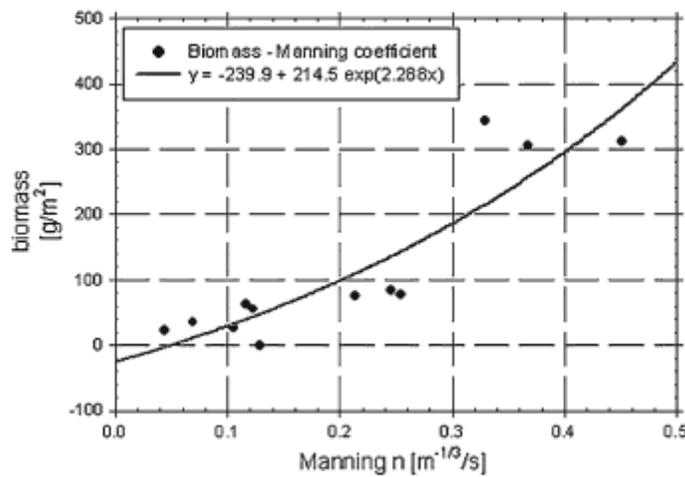


Figure 4 from Doncker et al. (2009) shows the relationship between biomass and stream flow (Manning coefficient,  $n$ ). As biomass increases, stream flow decreases.

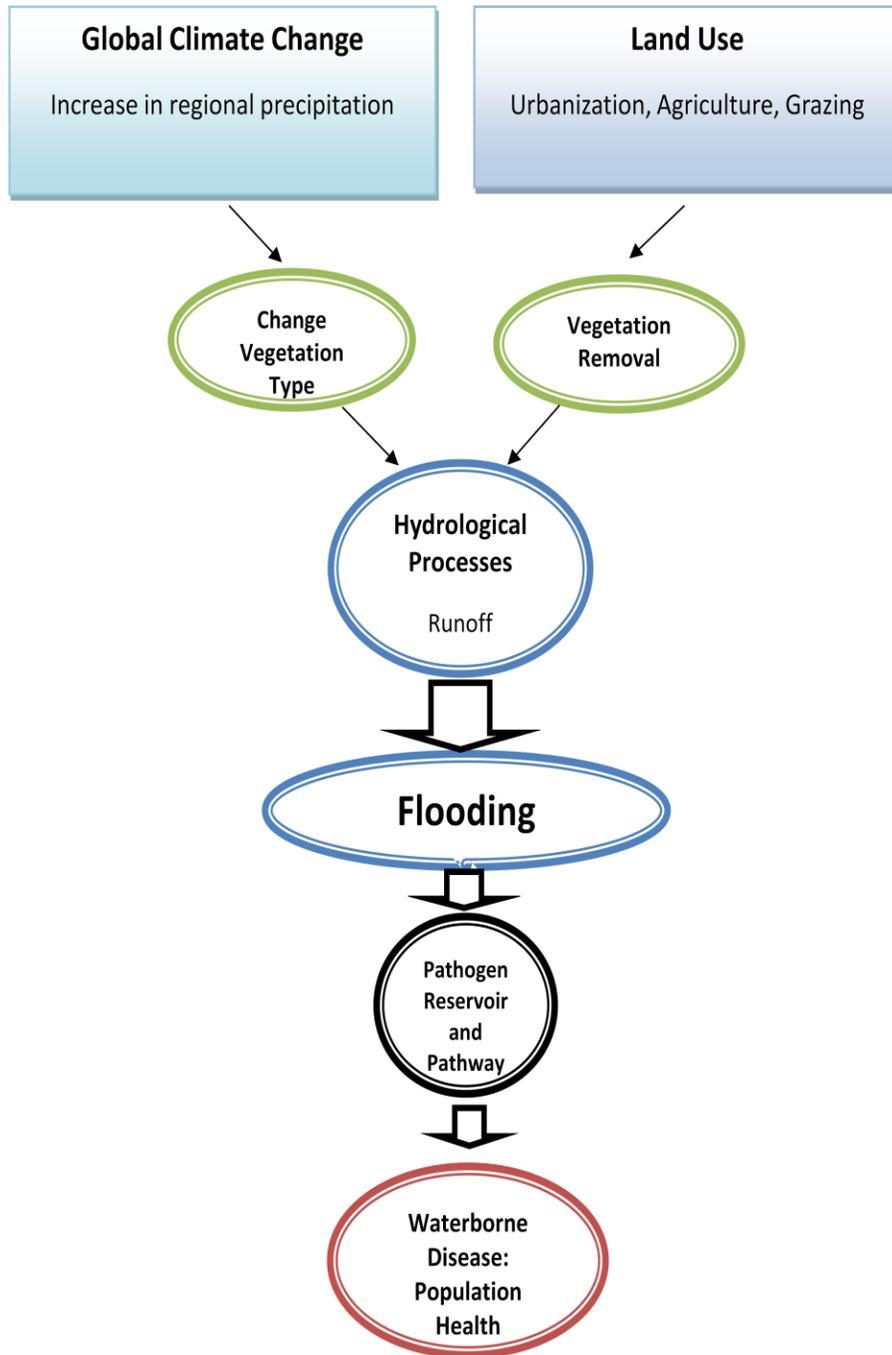
*Table 2 from Siddique et al. (1991) shows the rates and types of illnesses observed in the study population of 46, 470 persons affected by the 1988 flooding in Bangladesh. Diarrhea is associated with waterborne diseases, and can cause dehydration and death in infected persons.*

<b>Illness</b>	<b>No. per 100 patients</b>
<b>Watery diarrhea</b>	<b>16.3</b>
<b>Dysentery</b>	<b>3.8</b>
<b>Mucoid diarrhea</b>	<b>14.6</b>
<b>Respiratory tract infections</b>	<b>17.4</b>
<b>Intestinal worms</b>	<b>10.2</b>
<b>Fever</b>	<b>6.5</b>
<b>Skin infections</b>	<b>5.8</b>
<b>Injury with infections</b>	<b>5.1</b>
<b>Eye infections</b>	<b>2.2</b>
<b>Ear infections</b>	<b>1.8</b>
<b>Other diseases</b>	<b>16.3</b>

*Table 3 is a matrix of additional literature available regarding the incidence of waterborne disease outbreaks following flooding events.*

<b>Authors</b>	<b>Title</b>	<b>Year</b>	<b>Journal</b>
<b>Kondo et al.</b>	Post flood infectious diseases in Mozambique	2002	Prehospital Disaster Medicine 17(3): 126-33
<b>Wade et al.</b>	Did a severe flood in the Midwest cause an increase in the incidence of	2004	American Journal of Epidemiology 159(4): 398-405

	gastrointestinal symptoms?		
<b>Campanella, N.</b>	Infectious diseases and natural disasters: the effects of Hurricane Mitch over Villanueva municipal area, Nicaragua	1999	Public Health Review 27: 311-319
<b>Meier et al.</b>	An epidemic of presumed Acanthamoeba keratitis that followed regional flooding. Results of a case-control investigation.	1998	Archives of Ophthalmology 116: 1090-1094
<b>Shears, P.</b>	The Khartoum floods and diarrhoeal diseases.	1988	Lancet 3: 517



*Figure 5: Ecohydrological processes are impacted by land use and climate change, which affect vegetation type and presence. Changes in vegetation increase runoff, which can induce flooding. Flood waters host and transport pathogens, which impacts population health.*

## VI. References

- Anderson, B.G., Rutherford, I.D., Western, A.W. (2005). An analysis of the influences of riparian vegetation on the propagation of flood waves. *Environmental Modeling and Software* 21: 1290-1296.
- Brooks, A., Bierlet, G., Millar, R. (2002). The long-term control of vegetation and woody debris on channel and flood-plain evolution: insights from a paired catchment study in southeaster Australia. *Geomorphology* 51: 7-29.
- Campanella, N. (1999). Infectious diseases and natural disasters: the effects of Hurricane Mitch over Villanueva municipal area, Nicaragua. *Public Health Review* 27: 311-319
- Colindres, R., Jaine, S. Bowen, A., Domond, P., Mintz, E. (2007). After the flood: an evaluation of in-home drinking water treatment with combined flocculant-disinfectant following Tropical Storm Jeanne-Gonaives, Haiti. *Journal of Water and Health* 5.3: 367-374.
- Doncker, L., Trosch, P., verhoeven, R., Bal, K., Meire, P., Quintelier, J. (2009). Determination of the Manning roughness coefficient influenced by vegetation in the river aa and Biebrza river. *Environmental Fluid Mechanisms* 9: 549-567.
- Food and Agricultural Organization (2008). Definitions of Drylands and Dryland Farming. United Nations <<http://www.fao.org/docrep/012/i0372e/i0372e08.pdf>>.
- Friedman, J., Osterkamp, W., Lewis, W. (1996). Channel narrowing and vegetation development following a great plans flood. *Ecological Society of America* 77(7): 2167-2181
- Kondo, K., Seo, N., Yasuda, T., Hasizume, M. (2002). Post flood infectious diseases in Mozambique. *Prehospital Disaster Medicine* 17(3): 126-33
- Kundzewicz, K. Hirabayashi, Y. Kanae, S. (2010). River floods in the changing climate- Observations and projections. *Water Resources Management: 24* (2633-2646).
- Ludwig, J., Wilcox, B., Breshears, D., Tongway, D., Imeson, A. (2005). Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology* 86(2): 288-297.
- Meier, P., Mathers, W., Sutphin, J., Folberg, R., Hwang, T., and Wenzel, R. (1988). An epidemic of presumed Acanthamoebakeratitis that followed regional flooding. Results of a case-control investigation. *Archives of Ophthalmology* 116: 1090-1094
- Millar, R. (2000). Influence of bank vegetation on alluvial channel patterns. *Water Resources Research* 36(4): 1109-1118

Millennium Ecosystem Assessment (2005b). *Ecosystems and Human Well-being: Desertification Synthesis*. Island Press, Washington, D.C.

Millennium Ecosystem Assessment (2005a). *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, D.C.

Newman, B., Wilcox, B., Archer, S., Breshears, D., Dahm, C., Duffy, C., McDowell, N., Phillips, F., Scanlon, B., Vivoni, E. (2006). Ecohydrology of Water-limited Environments: A Scientific Vision. *Water Resources Research* (42).

Qadri F., Khan Al. Faruque ASG, Begum YA, Chowdhury F, Nair GB, Salam MA, Sack DA, Svennerholm AM. (2004). Enterotoxigenic Escherichia coli and Vibrio cholerae diarrhea, Bangladesh. *Emerging Infectious Disease* 11(7): 1104-1107.

Reid, Walter V. et al (2005). *Ecosystems and Human Well-Being: Millenium Ecosystem Assessment*. Chicago: Island Press.

Scanlon, B.R., Levitt, D.G., Reedy, R.C., Keese, K.E., Sully, M.J. (2005). Ecological controls on water-cycle response to climate variability in deserts. *Proceedings of the National Academy of Science*, 102(17): 6033-6038.

Shears, P. (1988). The Khartoum floods and diarrhoeal diseases. *Lancet* 3: 517

Siddique A.K., Baqui, A.H., Eusof, A. and Zaman, K. (1991). 1988 Floods in Bangladesh: Patter of illness and causes of death. *Journal of Diarrhoeal Disease Research* 4: 310-314.

Smith, D. (1976). Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. *Geological Society of America Bulletin* 87: 857-860.

Tongway, D. J., C. Valentin, and J. Seghieri, editors (2001). *Banded Vegetation Patterning in Arid and Semiarid Environments: Ecological Processes and Consequences for Management*. Springer-Verlag New York, Inc.

United States Environmental Protection Agency (2002). Excess effluent stream flow infiltration routing analysis methodology. *Brown and Caldwell*  
<<http://www.epa.gov/Border2012/infrastructure/bisbee/appendixd.pdf>>.

Wade, T., Sandhu, S., Levy, D., Lee, S., LeChevallier, M., Katz, L., Colford, J. (2004). Did a severe flood in the Midwest cause an increase in the incidence of gastrointestinal symptoms? *American Journal of Epidemiology* 159(4): 398-405