Chapter 2
Literature Review

2.1 Introduction

Researchers have undertaken a number of studies to analyze hydrologic response to different land-cover distributions. It is well known that urbanization causes increases in runoff volume and peak flows and decreases in time of concentration and groundwater recharge. However, a limited number of studies have been done that relate variability in stream hydrologic conditions to stream health. The objective of this chapter is to critically examine the studies that describe the relationship between land use changes in a watershed and stream health. For this purpose the studies been classified into the following categories:

i) studies that directly link land cover changes to stream health
ii) studies that relate land cover change to watershed hydrology
iii) studies that relate watershed hydrology with stream health

2.2 Direct Linkages of Land Cover to Stream Health

A number of researchers have studied the linkage between land development or urbanization and stream health by directly correlating watershed characteristics with stream health measures. These studies typically use several similar sized streams in a particular geographic region with different levels of stream health and assume that fish and other data in each stream would be approximately the same if the watershed had the same proportion of different land types. This assumption of transferability of stream data across watersheds is heavily debated in many circles.

Schueler (1994) suggests using imperviousness as a physical watershed variable for assessing the impacts on stream health. The author recommends a threshold for stream degradation beginning at 10 to 20% imperviousness. This recommendation is based upon the compilation of stream health measures linking imperviousness with channel erosion (10%), habitat quality (10 to 15%), macroinvertebrate diversity (10 to 15%), and fish habitat quality (8 to 12%).

Wang et al. (2000) compared Index of Biotic Integrity (IBI) scores and fish species with urbanization. A negative correlation was found between the IBI scores and fish species with a stream health threshold at 10% imperviousness. The authors also report another study showing a threshold for channel stability at a 10% level of imperviousness.

Finkenbine et al. (2000) used total impervious area in the watersheds of eleven Vancouver streams as a measure to evaluate stream health. The relationship between total impervious area and a decrease in streambed fine sediment indicates a resultant increase in cover (visual or physical protection of biota). A threshold for low summer flows was found at 40% total impervious area while a threshold for a significant decrease in large woody debris, a form of fish cover, was found at 20% total impervious area.

Blaha et al. (2000) compared benthic Index of Biotic Integrity (IBI) and fish IBI with physical watershed variables such as impervious surfaces, land use categories, stream road crossings, wetlands, and riparian buffers. The authors found variables related to impervious area as the best predictor of stream health.

May and Horner (2000) considered total impervious percentage to represent urbanization and related this value to habitat and stream health indicators. Initial findings show that riparian corridors are related to stream ecological health.

Stancil (2000) evaluated 43 sites in the Upper Roanoke River Watershed in Virginia comparing land use types with in-stream conditions. Disturbed land percentage was correlated with a multimetric index based on fish communities. The multimetric index score showed a negative relationship up to 10% disturbed land, after which additional land disturbance showed no effect.

Wang et al. (1997) analyzed 103 Wisconsin streams to study relationships between land use and habitat quality and biotic integrity. Significant correlations between habitat quality and IBI scores and land types were found, with forested land positively correlated and agricultural land negatively correlated. A threshold of 10 to 20% urban land use was found for low IBI scores.

2.3 Linkages of Land Cover to Hydrology

Although the effects of land use changes on hydrologic parameters like total runoff, storm peaks, etc. are well known, this section reviews some recent studies in this area.

Barringer et al. (1994) used two streams in New Jersey with different amounts of urbanization to evaluate the significance of trends in baseflow and overland runoff. Although the authors were not able to come to a conclusive determination from the data, an increase in flow variability with time was found.

Booth (1990) found that watershed urbanization increased runoff and stream discharge from a basin in western Washington causing increased channel erosion. The author further reported that the new "quasi-equilibrium" flow regime had the potential of causing channel expansion or catastrophic channel incision.

While evaluating the effectiveness of Best Management Practice criteria, Roesner et al. (2001) examined the importance of smaller, lower return period storms that are not controlled by local development regulations. Although municipalities generally focus on large storm events in the regulation of post-development storm flows, the author points out that smaller storms account for a vast majority of the total storm events and could be of greater importance. The elevated velocities of these smaller storms are left unchecked to erode the stream channel. It is further suggested to replace imperviousness with hydrogeometric and stream geomorphologic parameters when assessing stream health impacts.

Bosley et al. (2001) discussed impacts of four types of residential patterns using eleven different urbanization scenarios in a developing watershed in southwest Virginia. The authors found that for a fixed increase in population, low density development causes larger impacts on hydrologic parameters as compared to high density development.

2.4 Linkages of Hydrology to Stream Health

It is hard to deny the strong linkage between hydrology and lotic ecology. Fish and macroinvertebrates require enough water to provide cover, depth and other habitat characteristics, but can be stressed when high velocities wash away their eggs and spawning grounds and more energy is required for movement. The Flood Pulse Concept

(Junk et al. 1989) suggests that some regular flooding of a stream into its floodplain may be beneficial by providing an exchange of nutrients between the stream and riparian areas. Because the entire lotic ecological community lives in or around the stream and is dependent on flow characteristics of the stream, the stream health can also be linked to hydrology. Table 2.1 provides a summary of hydrologic variables found in literature linked to stream health.

Daily flow records from 38 streams in New Zealand were evaluated by Clausen and Biggs (1997) to determine a relationship between hydrological indices and stream biology. Thirty-four flow variables and seven biological variables were selected for the study. While several hydrological variables correlated with the biological variables for periphyton and invertebrate biomass and diversity, FRE_3 (a flood with flows three times higher than the median) was selected as the "most ecological useful overall flow variable." An increase in FRE_3 corresponds to a decrease in periphyton biomass, species richness and diversity and an increase in invertebrate density.

Poff and Allan (1995) attempted to find hydrological variables that can be used to differentiate stable and variable streams based on fish assemblage data from 43 sites in Wisconsin and Michigan. Four parameters, daily flow predictability, baseflow stability, coefficient of variation, and frequency of spates, were able to distinguish variable and stable streams. Many characteristic patterns of the fish found in either group surfaced and were discussed in detail. Generalists for example were found in greater numbers in the variable streams. The authors also recognized that the flow variability could reflect other variables of concern such as temperature.

Poff and Ward (1989) used 11 statistics from long term records of 78 streams to characterize discharge variability and predictability. Nine stream types were found and were distinguished by intermittency, flood frequency, flood predictability, and overall flow predictability. The authors found that flow variability can constrain ecological systems and prepared a table of specific reactions macroinvertebrates and fish could have to changes in hydrologic factors.

Poff (1996) attempted to classify streams based on flow variability, predictability, and extreme event analysis from long term records. Poff identifies ecologically relevant hydrological characteristics that should indicate differences in ecological communities. The variables allowed for classification of 10 stream types.

Bain and Loucks (1999) studied land use and water management effects on flow regime water quality, and biotic integrity. Habitat integrity indicators such as flow persistence, flow stability, thermal fluctuations, substrate stability, and substrate composition were used in suitability curves that are created from experience or other studies.

Horwitz (1978) used long-term daily discharge records of 15 streams to assess the relationship between variability and fish distribution patterns. Variability, measured by the coefficient of variation, was lowest in downstream sections. Variable rivers had the lowest headwater diversity, diversity increased the greatest longitudinally with rivers whose discharge variability increased the greatest longitudinally, and downstream sections with the least variability had the highest diversity. Horwitz concludes that these results support hypothesis relating "control to extermination-recolonization dynamics or interspecific competition mediated by temporal variability and habitat structure." A link between discharge and temperature variation due to volume is also discussed.

Jowett and Duncan (1990) used flow variability indices for New Zealand sites to group rivers based on habitat and biota. Longitudinal variability of depth and velocity increased at higher flow variability and rivers with higher flow variability had lower mean velocity for mean annual low flow, median flow, and mean flow. Strong associations were found between flow variability and periphyton communities and trout distribution and abundance and a weak association between flow variability and invertebrates. Velocity was found to be the most important variable due to associations to temperature, invertebrate and periphyton community structure, and trout distribution and abundance.

The relationship between riparian vegetation and flows is evaluated by Pettit et al. (2001). Water depth and duration of flows and the number of flood events per year significantly correlate with riparian vegetation measures. The river with higher flow variability showed a decrease in species richness and shrub cover and an increase in exotic and annual species with an increase in duration and flooding frequency.

Synthetic daily hydrographs were generated by Poff et al. (1996) based on historic precipitation. Precipitation was varied by +/- 25 %, the coefficient of variation of the precipitation was increased by a factor of 2, and temperature was raised 3 degrees Celsius in the four scenarios. The coefficient of variation had the largest effect, increasing the average runoff, flow variability, flooding frequency, and baseflow stability. Ecologically important hydrologic variables were separated into 3 categories for the study: mean flow conditions, high flow extremes, and low flow extremes. The authors postulated that deviance from the natural flow regime increases the effect on stream ecology.

Bunn et al. (1986) analyzed data from streams in Western Australia to develop relationships between spatial and temporal changes and macroinvertebrates. The highly predictable streams showed seasonal changes in species composition coupled with seasonal changes in discharge. Regression analysis showed a strong association between velocity and depth and changes in fauna along with some other variables such as cation concentration and temperature.

Hawkes et al. (1986) developed fish ecoregions based on fish assemblages for Kansas streams. Statistical analysis showed that mean annual runoff, mean annual growing season and discharge are the most important factors in identifying and separating the regions.

Ladle and Bass (1981) evaluated the changes that take place on a small chalk stream during a summer drying period. Plant, macrophyte, and invertebrate species that were tolerant to drying periods clearly took advantage of the dry situation. Species with high reproduction recovered quickest from the conditions.

Poff et al. (1997) found streamflow to be closely related to stream health as it controls many of the processes of a stream. Moving away from a stream's natural flow regime can have detrimental effects on a stream's ecology. The five major components of the flow regime are magnitude, frequency, duration, timing or predictability, and rate of change or flashiness. Because each stream has a unique flow regime, identical landuse can have different effects on ecology.

Power et al. (1988) summarized the current state of knowledge about biotic-abiotic interactions and discussed areas that require future work. Influences of local abiotic conditions such as oxygen levels and discharge variation throughout the water column and the effects on localized life are discussed. Discharge fluctuation was found to provide a "reset" allowing a change or renewal of species. Additionally, discharge variation can cause changes in water levels allowing additional habitat access to species at vulnerable life stages. However, catastrophic variations can serve to eliminate species if high or low flows repeatedly occur at critical life stages. Species can recover from catastrophic events using recolonization or regeneration tactics.

DiMaio and Corkum (1995) examine the relationship between hydrologic variability and freshwater mussels. Many of the factors effecting mussel distribution such as sediment type, water velocity, water depth, water level variation, and stream size are related to discharge. Therefore, different mussel communities were found to exist for the two types of flow variability identified, event responsive and stable. The authors believe that "flow-related stream attributes" can be used to predict mussel distribution.

Fitzpatrick et al. (2000) studied the relationship of riparian corridor widths and hydrologic variability and agricultural stream biota. Preliminary results from the study indicate that fish were influenced by riparian corridor width, land use and geology, invertebrates were influenced by baseflow, habitat, and riparian corridor width, and algae were influenced by land use, riparian corridor width, and hydrologic conditions. Some relationships between selected variables were indicated by the data including flow variability with diatom tolerance and Wisconsin habitat scores.

Grossman et al. (1982) selected 12 years of abundance and trophic structure data of an Indiana stream to characterize species abundance patterns. A stochastic model is found to adequately depict assemblage dynamics and environmental instability is identified as a major "causal agent" in ecosystems. The timing and severity of floods and their correspondence with critical times in fish lifecycles are discussed as a possible reason for the changes seen in the stream assemblage. The authors note that other work has shown significant effects from small scale floods and droughts.

Harvey (1987) used a real storm event and a simulated storm event in an artificial channel to evaluate flooding displacement on fish. Small fish were found to be much more susceptible to drift than larger fish and the timing and characteristics of flood events were found to have an effect on species reproduction.

Minshall and Peterson (1985) suggest a theory for macroinvertebrate community structure. Species accumulation is separated into an early non-equilibrium, stochastic phase that is mostly effected by drift and a later equilibrium phase that is deterministic by nature. Disturbed streams are theorized to take longer for species accrual.

Reice (1985) evaluated macroinvertebrate recovery from disturbance by tumbling patches of cobbles at different intervals to simulate different disturbance levels. Large reductions in populations were seen after a disturbance, but a full, quick recovery was evidenced in four weeks time. However, additional disturbances prolonged the recovery time. Disturbance was identified as "a major determinant in lotic community structure and species diversity." Reice also acknowledged the possibility of a stream being in a constant state of recovery.

Ross et al. (1985) discussed environmental perturbation impacts on fish community structure by selecting two streams, an intermittent prairie stream and a permanent, groundwater fed upland stream. Stability, the constancy in number of organisms, and persistence, a qualitative measure, were used in the analysis based on fish data. Both streams had a high persistence, but different stability (with the prairie stream being less stable). The data from the study supports the relationship between an increase in environmental variability and a corresponding greater increase in faunal variability. While a summer drought did not significantly change the overall fish assemblage, showing persistence, the harshness of variable systems is found to limit colonization and species continuance resulting in a stream with more tolerant species. Stability of assemblages can be a result of resistance, withstanding disturbance, or adjustment stability (the ability for rapid recovery).

Schlosser (1985) analyzed the fish assemblages of a second order stream in Illinois during years with different types of flow regimes. While adult fish abundance changed little, marked differences were seen in the juvenile fish. Juvenile suckers and darters were less affected, while minnows and sunfish were more abundant in stable conditions. Juvenile abundance was most affected in fish with longer breeding seasons and stable conditions produced higher species richness. Reproductive behavior and physiology and habitat requirements are reasons cited for species with lower abundance in higher flow variable systems. Schlosser suggests that stochastic processes govern juveniles while deterministic processes govern adults.

2.5 Summary and Conclusions

Literature for studies linking land cover changes to stream health, land cover changes to watershed hydrology, and watershed hydrology to stream health have been summarized. Studies linking land cover changes directly to stream health ignore the significance of the unique hydrologic processes of each watershed and receiving channel and assume that the correlation between the indirectly related land use and stream health variables can be transferred between similar watersheds and streams. Studies relating land cover to watershed hydrology have been well documented and the linkage between the two variables is relatively well understood. However, these studies do not further the analysis to include the impacts on stream health. Studies relating watershed hydrology (mostly channel flow regime) with stream health parameters stop short of exploring how the changes in the flow regime have occurred. These studies indicate that high flow, low flow, overall flow variability, and predictability and seasonality are the major ecologically significant hydrologic statistic groups.

Clearly, there is a need for studies linking development with stream health impacts using hydrologic processes. Therefore, this study will begin to provide such a linkage by modeling the impacts of residential development patterns on stream health using the HSPF model to simulate hydrologic changes. This study will achieve a very high level of hydrologic data resolution and will simulate a wise range of climatic conditions by executing 43 year hourly runs in HSPF. To the knowledge of the author, no other study has undertaken simulations of the length at this timestep for purposes of comparing stream health impacts of development patterns.

Table 2.1 List of Hydrologic Variables with Linkages to Stream Health

Source	Stream Health Characteristic Linkage	Variable	Variable Description/Definition	Additional Notes
Horwitz, 1978	Significant relationships with fish diversity	Coefficient of Variation	Standard deviation of flow divided by the average	Variability
		Logarithmic Coefficient of Variation	ln(Coefficient of Variation + 1)	Variability less sensitive to large floods
Poff and Ward, 1989	Stream classification based on discharge variability and predictability that cause responses from invertebrates and fish	Annual Coefficient of Variation	Standard deviation of flow divided by the average	Overall Flow Variability
		Predictability	Defined by Colwell (1974)	
		Flood Frequency	Number of floods (greater than 2 year return period) per year	Pattern of Flood Regime
		Flood Interval	Median interval between floods	
		Flood Duration	Mean duration of floods	
		Index of Flood Predictability	Maximum proportion of floods occurring in any 60 day common period	
		2nd Index of Flood Predictability	Maximum number of 365 days common to all years that floods do not occur	
		Index of Seasonality	Median day of all days of the water year where floods occur	
		Zero Days	Number of zero flow days	Pattern of Intermittent Conditions
		Low Flow	Average(Ln(24 hour annual low flow))/ Ln(mean flow))	

Jowett and Duncan, 1990	Stream classification based on flow variability; Strong associations with periphyton communities and trout distribution and abundance, and weak associations with invertebrates	Baseflow Index	Baseflow to runoff ratio	Overall Flow Variability
		Coefficient of Variation	Standard deviation of flow divided by the average	
		Mean to Median Ratio	Mean flow divide by median flow	
		Mean of Annual Maxima Divided by Median Flow	Mean of the annual maxima flow divided by median flow	Range of Flow
		Mean of Annual Minima Divided by Median Flow	Mean of the annual minima flow divided by median flow	
		Coefficient of Variation of Annual Maxima	Average annual maxima flow divided by the standard deviation of the annual maxima	
		Coefficient of Variation of Annual Minima	Average annual minima flow divided by the standard deviation of the annual minima	
Richards, 1990	Measures of flow variability for monitoring non point source pollution	Coefficient of Variation	Average flow divided by the standard deviation	
		10/90 Percentile Ratio	10th percentile flow divided by 90th percentile flow	
		20/80 Percentile Ratio	20th percentile flow divided by 80th percentile flow	
		25/75 Percentile Ratio	25th percentile flow divided by 75th percentile flow	
		0.8S	(90th percentile flow - 10th percentile flow) divided by the mean	
		0.6S	(80th percentile flow - 20th percentile flow) divided by the mean	
		0.5S	(75th percentile flow - 25th percentile flow) divided by the mean	
Poff and Allan, 1995	Stream classification based on fish assemblage data	Daily Flow Predictability	Defined by Colwell (1974)	Distinguishes between stable and variable streams as defined by fish assemblage data
		Baseflow Stability	Lowest daily flow divided by the mean daily flow	
		Coefficient of Variation	Standard deviation divided by the average	
		Spate Frequency	Average number of spates (bankfull events) per year	
		Spate Predictability	Proportion of all spates falling in 60 day seasonal windows	
		Spate Free Period	Maximum proportion of the year that no floods occur throughout the record	

Poff, 1996	Stream classification based on ecologically relevant variables for flow variability, predictability, and extreme events	Coefficient of Variation	Standard deviation of flow divided by the average	Flow Variability and Predictability
		Predictability	Defined by Colwell (1974)	
		Flood Frequency	Average number of events (Return Period >1.67 years) per year	High Flow
		Flood Duration	Average number of days above bankfull	
		Seasonal Predictability of Flooding	Maximum proportion of floods occurring in any of 6 seasonal 60 day periods	
		Seasonal Predictability	Maximum proportion of the year that no floods occur throughout the record	
		Baseflow Index	Average annual ratio of lowest daily flow to the mean daily flow	Low Flow
		Extent of Intermittence	Average annual number of days with zero discharge	
		Seasonal Predictability of Low Flow	Proportion of 1 day low flows with a return period greater than 5 years falling in any of the 6 seasonal 60 day periods	
Poff et al., 1996	Ecologically important hydrologic variables	Mean Daily Discharge	Mean of daily discharges	Mean Flow
		Coefficient of Variation of Daily Flow	Average divided by the standard deviation	
		Predictability of Daily Flow	Defined by Colwell (1974)	
		Flood Frequency	Bankfull events per year	High Flow
		Flood Predictability	Ratio of floods occurring in a 60 day period compared to all flood throughout the year	
		Flood Free Period	Maximum fraction of the year without bankfull events	
		Baseflow Index	Average of annual minimum flow to mean flow	
Clausen and Biggs, 1997	Periphyton biomass, species richness and diversity; Invertebrate density	FRE3	Floods of magnitudes three times or greater than the median flow	Positive relationship with periphyton and negative relationship with invertebrates

Bain et al., 1999	Habitat integrity indicators	Flow Persistence	Above or below 90 day threshold of no flow	
		Flow Stability	Percent exceedence (10%-90%) divided by the mean	
Fitzpatrick et al., 2000	Diatom tolerance	2 Year Flood/Baseflow Ratio	Ratio of the 2 year return period flood to baseflow	Related to a ratio of pollution tolerant diatoms to total diatoms and a regional habitat score
Pettit et al., 2001	Significant relationship with riparian vegetation measures; Associations with species richness, shrub cover, and exotic and annual species	Coefficient of Variation	Standard deviation divided by the average	Flow Variability
		Predictability	Defined by Colwell (1974)	
		S80	Difference between the 90th and 10th percentile divided by the 50th percentile	