of infiltration to groundwater, evapotranspiration to the atmosphere, and runoff to the down-slope hydrologic network of wetlands, streams, rivers, etc. Where impacts and imbalances already exist, communities can set goals to restore elements to functioning levels associated with a healthy environment.

Social Goals: Social goals in the context of sustainable water infrastructure include things like maintaining a clean and abundant water supply, safe and secure food supply, clean and stable energy supply, healthy and enjoyable living (including working and recreational) space, social connectedness, and environmental justice. Many communities likely would say that they traditionally support goals such as providing clean and abundant water supply, and a safe and secure food supply. What is different, however, is considering them simultaneously with the other goals to try to accomplish the environmental, social and economic goals collectively. Additionally, water infrastructure management decision-making has not always prioritized goals involving enjoyable living, social connectedness and environmental justice. These are part of the new way of thinking to support sustainable communities.

Economic Goals: From an economic standpoint, the existing paradigm typically looks for low cost alternatives without considering the value of the services offered and other community objectives. The goals recommended under the new paradigm include some other economic considerations. For example, having water systems that are self-supporting (i.e., customers pay the full cost), and ensuring that the value of water infrastructure services exceeds the monetary cost. Another new paradigm economic goal is building in resilience; for example, to avoid potential future high cost of infrastructure repair/replacement following extreme events and the cost to the community when services are disrupted due to damage. Additionally, facilitating economic growth through the promotion of clean and green industry both helps provide local solutions to environmental challenges while providing economic benefits across the workforce.

Communities can use the overarching goals listed above as a starting point in setting local water sustainability goals. Ideally, this would be done in conjunction with local comprehensive planning efforts and accompanying land use planning as these can provide excellent vehicles for communities to define and coordinate policy on a range of long-term issues affecting water such as land use, transportation, environment, housing, water and sewer infrastructure, parks, waste disposal, etc. Alternatively, a local sustainability task force might be appointed to establish sustainability goals (including but not limited to water), which can later be incorporated into comprehensive planning efforts and other more specific infrastructure and land use plans.

New Paradigm Component 2 – Operate by Sustainable Infrastructure Principles

A considerable amount of time was spent by the research team and retreat participants to identify the core principles that constitute this new way of thinking. Many of the project's advisory panelists said that these thoughts are among the most important outcomes of the retreat to communicate because they reflect the type of thinking and action that communities need to follow to successfully achieve a strong triple bottom line (i.e., the environmental, social and economic goals listed above). While the principles were derived from discussion involving the two case study communities, they are recommended for any community striving for sustainability and as such they constitute the second component of the research team's definition of the new paradigm.

1. *Value the resource*: Water is vital for life, and water in its various forms (including stormwater and wastewater) contains valuable resources such as nutrients, energy and carbon. Communities need to value the entire water cycle, recognizing the importance of precipitation, interception, storage, infiltration, runoff and evapotranspiration processes to sustaining a strong triple bottom line. There is also social and economic value to the beauty and community that water can create (e.g., parks, beaches, hiking and boating areas).

2. *Aspire to higher objectives that spawn better outcomes*: Water infrastructure designs should add value and provide multiple benefits (for example, natural treatment systems that double as recreational spaces or bioretention areas that serve as public art for the community). A key part of this higher objective is integrating the built environment with the natural environment (for example, using native soils and vegetation as green infrastructure to capture and treat stormwater runoff from the built environment). Under this principle, communities should consider life cycle impacts of actions beyond their local boundaries (for example, controlling water quality in the Ohio River to minimize the hypoxic zone in the Gulf of Mexico).

3. *Consider context at multiple scales* (on site, watershed, regional, and global): For example, excess runoff from a developed site can erode soil on site, the excess runoff in turn destabilizes downstream channels adding further sediment to the water column at the small watershed scale, and the pollutants associated with the sediment combine with other runoff to impact water quality at the regional scale (e.g., sediment-borne nutrients in the Mississippi Basin feed algae in the Gulf of Mexico leading to large segments of the Gulf that are devoid of aquatic life).

4. *Build intellectual infrastructure*: Use of research and demonstration projects and the compiling of a knowledge base of new technological approaches will facilitate new ideas for successful and sustainable water infrastructure management. Additionally, communities need to build knowledge about their specific water resource issues by investing in monitoring and modeling systems that can predict future conditions, support performance standard development, and help evaluate alternative water infrastructure management options.

5. *Integrate water management decisions with all aspects of community planning and development*: Valuing water and understanding that most infrastructure projects will affect the natural hydrologic cycle means addressing these issues up

front in the planning and design phases. In particular, land use planning and water resource management must be coordinated.

6. *Share responsibility and risk throughout the community*: Stakeholders are engaged in the decision-making process from the beginning. An inclusive and transparent process is more likely to result in shared responsibility and risk, including building and relying on local capital for creative and science-based decision making. This also creates a greater "stake" in the outcome, which helps to focus efforts and potentially serve the overarching economic justice goal, deriving solutions that share cost across the community.

7. *Recognize true costs and maximize value/benefits*: Use full life cycle costs over a long-range (e.g., 100-year) life cycle to evaluate water resource management decisions. This information takes into consideration the external social and environmental impacts; communities are more likely to be able to adequately assess whether they are meeting their overarching goal of having the value of services exceed the monetary cost of alternatives.

8. *Choose Smart, Clean and Green*: "Smart" infrastructure uses information and signaling (e.g., real-time meters) to modify water use behavior and treatment supporting efficient use of resources. "Clean" infrastructure uses resources and methods that are resource efficient and avoid use of harmful substances. "Green" infrastructure learns from and works with nature and uses soil and vegetation to manage water and restore natural ecosystems. Smart, clean, and green approaches are directly linked to the overarching environmental, social and economic goals because they emphasize efficiency, conservation, low environmental impact, healthy living, and an economy with more emphasis on clean industry.

9. *Adapt and evolve*: Communities need to implement management approaches that monitor performance so that progress toward goals can be assessed and corrections to plans, designs and operations can be made as needed.

New Paradigm Component 3 – Adapt and Integrate Technological Architecture

A fundamental theme coming out of the retreat sessions associated with new paradigm technologies revolves around integration of resource management technologies and strategies as well as integration of technological approaches and architectures. Technological architecture involves the placement and design of various components of our water infrastructure systems – where should treatment systems be located and how big should they big, how do system integrate with the natural work and other built environments, and what is the role of controls and monitoring systems in this architecture? Integrated resource management describes the coordinated development and management of water, land, and related resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Water (and other resources—nutrients, carbon, energy, etc.) can be more sustainably managed by considering the system holistically, rather than separately as specialized elements (e.g., water supply versus stormwater versus wastewater versus aquatic ecosystems) with limited interrelationship.

Under a new technological framework rooted in integrated management, a number of movements or fields of study and practice continue to develop. These movements are not mutually exclusive—applied collectively, they support new and exciting infrastructure system architectures that combine closed loop resource recovery at localized scales with centralized management and oversight informed by smart and responsive monitoring and control systems. Existing infrastructure may be repurposed for new functions, such as the case with a wastewater collection and treatment system managing residuals and providing backup for satellite water reuse. For the purposes of this project, the research team organized the new technological approaches into the following four categories:

1. *Resource efficiency, recovery and recycling*—in addition to water, other waste-related resources should be used as efficiently as possible, while resources in waste should be recovered and recycled.

2. *Distributed resource management*—a combination of infrastructure scales, from decentralized to centralized, should be used as appropriate; managing resources closer to the source of generation and reuse opportunity is often more efficient.

3. *Multi-benefit infrastructure solutions*—infrastructure solutions can and should provide a multitude of benefits spanning the triple bottom line of environmental, societal and economic attributes.

4. *Design new water systems that mimic and work with nature*—these systems will both protect public health and safety and will restore natural and human landscapes. Nature and man can cooperate to rebuild healthy communities and restore natural ecologies through incorporation over time of sustainable infrastructure designs and principles, with water at the center of these designs.

While each approach has merit on its own, the new paradigm emphasizes integration across the spectrum of approaches as appropriate for the context within each community. Additionally, since technological approaches are applied with the objective of attaining certain levels of performance to achieve triple bottom line goals, the new paradigm emphasizes monitoring outcomes and adapting the technological approaches used to enhance performance over time.

New Paradigm Component 4 – Build the Institutional Capacity

To shift to the new water infrastructure management paradigm, the site-scale innovation being driven by the green building movement needs to be brought together with integrated infrastructure and watershed management planning. This shift will depend, in great part, on institutional changes that help build the capacity to support sustainable operations at the community scale.

During the project retreat, a significant portion of time was spent on discussing various aspects of institutional factors that play an important role in water infrastructure management decision-making including: integrated planning, community engagement, regulatory and programmatic change, and management and financing. For each of these factors, breakout groups for Northern Kentucky and Tucson-Pima County identified opportunities and challenges for each case study community building off of their existing management foundations to help them achieve triple bottom line goals. The results of these discussions and follow up by the research team led to defining and developing several key areas where communities in general can focus on building their institutional capacity, including:

- Integrated Planning and Smart Growth
- Watershed Scale Planning and Management
- Full Life-Cycle Costing
- Improved Regulations
- Enhanced Community Engagement
- Investment in Intellectual Capital
- Market Mechanisms

New Paradigm Component 5 – Evaluate Outcomes and Adapt

Outcomes are often uncertain when charting new waters, so monitoring results iteratively allows decisions to be optimized over time to reduce uncertainty and improve the outcome. Those decisions/projects are evaluated against the triple-bottom line objectives, which requires selecting indicators for each or representative objectives.

Targets or performance standards that have been set for the indicators provide the basis for evaluation. If targets or performance standards are not met, evaluators move into a diagnostic phase (where does the problem lie?—goals? technologies? application? policies? operations?). Based on the lessons learned from this diagnostic review, and any new information (e.g., related new research), stakeholders identify solutions or new approaches to take for the next iteration. Selecting the refined or new approaches will likely involve using the support tools (e.g., watershed models, full life-cycle costing) for infrastructure projects to provide triple bottom line justification. The community then moves forward to implement those changes, and the evaluation process cycles through another iteration.

DISCUSSION AND CONCLUSIONS

Water sustainability cannot be accomplished by adding up the excellent results of separate institutions – an integrated plan where resources are pooled and challenges and opportunities are explored will yield more sustainable solutions in many cases. Likewise water sustainability cannot always be accomplished by perfect compliance with a list of one-by-one rules. Principally the new paradigm recognizes the value of water and institutes an integrated management framework to facilitate meaningful implementation of sustainable measures.

Many factors are driving communities to become more sustainable. Current water infrastructure management practices, while helping to build our communities and improve environmental and social conditions, are not capable of achieving our environmental, economic and social goals. Communities that embrace sustainability goals will need to operate under a new set of principles, anchored in recognizing the value of water and integrating planning, design, and implementation across multiple institutions and programs. An initial set of these principles have been defined for communities to adopt and adapt as they move forward.

Despite the challenges that have been identified by the research team and retreat participants, there are important actions that can be taken in every community to start building the foundation and architecture for new paradigm sustainable water infrastructure management. Implementing near-term opportunities (i.e., integrating water master planning, revising building and zoning codes, leading by demonstration, and building intellectual capital) can have immediate results. However, a number of challenges and actions will take longer to address (i.e., developing water performance standards, establishing new ownership and maintenance models, and developing funding/market mechanisms to leverage and expand capacity) and require leadership, capacity-building, and persistence.

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Land Use Change and Its Impact on Water Resources in East River Basin, South China

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ABSTRACT

Using hydrological data of the East River Basin, South China, over the past five decades, this paper analyzed the impact of land use changes and vegetation cover changes on the hydrological system of the basin. It was found that the Normalized Difference Vegetation Index (NDVI) in the Basin is not significantly correlated with natural runoff, annual evapo-transpiration or runoff coefficient. Changes in the conditions of the underlying surface of the river basin arising from land use/land cover changes are the primary factor impacting upon runoff changes in the East River Basin and are the main reason for the increase in runoff in the river basin. Changes in the hydrological system of the East River Basin are subject to the impact of complicated factors, typically the joint impact of climatic changes and human activities.

Key words: land use change; impact; hydrological system; East River Basin of China

INTRODUCTION

The study of the relationship between vegetation cover and rainfall, runoff and sediment has become a part of the focal point of hydrology in recent years (Yu, Yan and Li, 2002; Lu and Huang, 2003) even though few research reports can be found in Southern China. So far, some strides have been made in the research of the correlation between the NDVI spatial change of the Pearl River Basin and its sub-river basins (Wang, Chen and Li, 2006; Wang and Chen, 2006). However, such research is largely focused on the correlation between NDVI and rainfall and temperature, and there are few cases of research on the correlation between the NDVI changes and runoff changes in the river basin. As a matter of fact, the utilization of water resources in the river basin exhibits regional characteristics. Thus, it is particularly significant to study the characteristics of the NDVI changes in each sub-zone of water resources utilization, as well as its correlation with regional rainfall and runoff, and to identify the regional differences of NDVI in relation to the response of rainfall and runoff (Li and Yang, 2004). This paper attempts to reveal the impact of changes of land use and vegetation cover on the hydrological system within the East River Basin in Southern China.

The East River, located at 113°52’-115°52’E and 22°38’-25°14’N, is one of the largest streams in the Pearl River Basin (Figure 1). Stretching 520km from its headwaters to Shilong, the East River drains an area of 27,040km^2. The administrative units that the East River flows through include Heyuan, Huizhou, Dongguan, Shenzhen, Shaoguan and Meizhou Cities. Table 1 shows the percentage of these cities' land in the East River Basin.

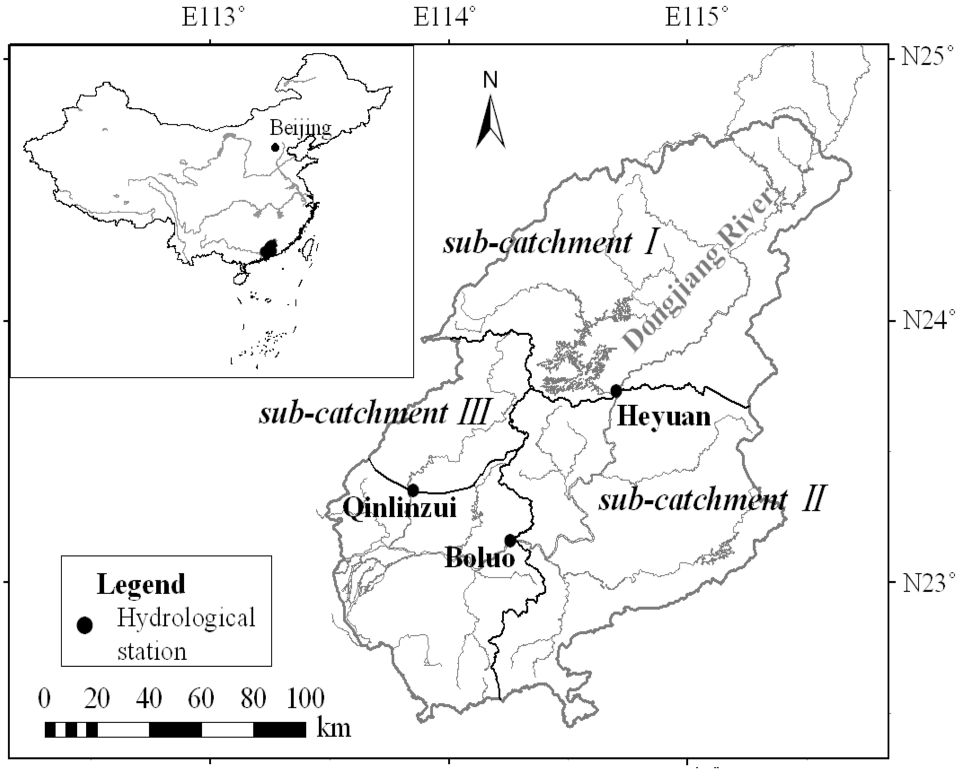

Figure 1. Water System of the East River Basin.

Table 1. Percentage of the Cities' Land in the East River Basin.

City	Total Land Area of the City (km^2)	Land Area of the City in East River Basin (km^2)	Percentage of the City's Land in East River Basin (%)
Total	65,647	23,540	35.86
Heyuan	15,665	13,605	86.8
Huizhou	11,142	7,013	62.94
Dongguan	2,493	6,17	24.75
Shaoguan	18,639	1,264	6.78
Meizhou	15,844	272	1.72
Shenzhen	1,864	769	41.26

The annual rainfall of the East River Basin ranges from 1,500mm to 2,400mm, averaging 1,750mm, with a variation coefficient of about 0.22. Geographically, the middle and lower reaches of the East River usually receive more rainfall than its upper reaches, and the southwestern parts of the river basin generally have ampler rainfall than its northeastern parts, with rainfall descending from south to north. The water surface evaporation of the East River Basin ranges from 1,000mm to 1,400mm, averaging about 1,200mm. Geographically, the southwestern parts of the river basin have more evaporation than its northeastern parts.

Data collected from 1954 to 2000 by the Boluo Station indicate that the East

River Basin has an average annual runoff of 23.79 billion m^3, with the runoff of the wettest year exceeding that of the driest year by 261 percent. In a given year, the flood season (from April to September) accounts for 75 to 85 percent of the year's total runoff. The total amount of groundwater in the East River Basin is estimated at 6.398 billion m^3.

Plants growing the East River Basin are mostly South Asian tropical monsoon rain evergreen broadleaved trees, South Asian tropical grass, and artificial evergreen conifers. With a forest coverage rate of 58.5% in Huizhou City and 71.7% in Heyuan City, most mountainous and hilly areas have been forested. However, vegetation coverage rate remains low and soil erosion is serious in Longchuan and Zijin Counties in the upper reaches of the East River and in some parts of Huidong and Huiyang in the Xizhi River Basin, making these areas the first priority for soil erosion abatement programs.

SOURCE AND PRE-PROCESSING OF DATA

(1) TM Remote Sensing Image Data

Data on land use and land cover have been sourced from the calibrated and deciphered materials from two phases of Landsat MSS/TM/ETM^+ remote sensing. The imaging was performed in the early 1980s (in 1982, 1983 and 1984) and at the turn of the 21st century (in 1999, 2000 and 2001), with the spatial resolution of 79m or 30m. The data have been sourced from the joint laboratory of the Global Observing Laboratory and the Geosciences and Resources Institute at the University of Maryland, and are freely available on the Internet (http://glcf.geodata.cn/).

(2) Field Investigation Data

In August 2005 and November 2006, field investigations were conducted in the headwater area and in the middle and lower reaches of the East River respectively. Using GPS, 57 sampling points were investigated, and the type of vegetation, the state of vegetation cover, altitude, the type of land use, and the level of human interference were documented in detail. Data from field investigations were sorted out and a database was built.

(3) Hydrological Data

Over a time span from January 1956 to December 2000, hydrological data of the three flow measuring stations in the East River Basin used in this paper are mainly sourced from the database and hydrological yearbooks provided by the Guangdong Provincial Hydrological Bureau. The undisturbed natural data of yearly and monthly runoffs were obtained by reestablishing the amount of industrial and agricultural water consumption and the storage variables of the reservoirs on the basis of measuring data.

(4) Topographical Data

Topographical data used in this paper are the data on the 1:250,000 altitude isolines as provided by the National Fundamental Geographical Information Center. The data were rasterized in the ARCGIS software, thereby creating the raster data on the topography of the river basin, with the size of the raster set at 100m. In addition, SRTM 90m DEM data from CGIAR-CSI which are freely available on the Internet (GTOPO30) were used, and the river distribution vector data from the 1: 250,000 full-feature data provided by the National Fundamental Geographical Information Center were also used.

In order to facilitate the analysis of the impact of DEM with different resolutions on the simulation results, this paper also used China's topographical raster data from the GTOP030 of the United States Geological Survey (USGS), which have a resolution of 1 km (GTOPO30 Data Source). GTOP030 is a global digital elevation model produced by the Earth Resources Observing Satellite (EROS) of the United States Geological Survey (USGS).

(5) Other Data

The GLO-PEM analogue data come from the NPP (Net Primary Productivity) data of the University of Maryland which covers China (Prince and Small, 2001). These data involve a span of time from 1981 to 2000 and have a temporal resolution of 10 days and a spatial resolution of 8 km×8 km. Data used in this research were extracted from the monthly data of the studied region over a 20-year period, using the defined boundaries of the Pearl River Basin, on the basis of NPP data covering China and with the support of the ArcGIS software. The extracted data were then made into the Pearl River Basin's NPP digital images which are consistent with vegetation data in terms of projection and temporal and spatial resolutions, in order to facilitate the analysis of the NPP temporal and spatial distribution of all types of vegetation.

LUCC RESEARCH METHODS

The rate of land use changes represents the dynamic degree of changes in land use of a certain type in a specific region. The dynamic degree of change in land use of a certain type in a specific region is highly valuable in comparing the regional differences in the region's land use change and in forecasting the future trends of land use change (Zhu and Liu, 2003).

(1) Dynamic Degree of Single Type of Land Use

The dynamic degree of single type of land use represents changes in the quantity of land use of a certain type over a given period of time in a certain region. It can be expressed with

$$\mathrm{K} = \frac{\mathrm{Ub} - \mathrm{Ua}}{\mathrm{Ua}} \times \frac{1}{T} \times 100\% \tag{1}$$

Where, Ua and Ub represent the quantity of land use of a certain type at the beginning and end of the period under research, respectively; T represents the length of time under research. When T is set as year, K represents the rate of yearly change in land use of a certain type.

(2) Dynamic Degree of Integrated Land Use

The dynamic degree of integrated land use of the region represents the rate of land use changes in the region. It can be expressed by

$$\mathrm{LC} = [(\sum_{i=1}^{n} \Delta LU_{i-j})/2\sum_{i=1}^{n} LU_i \times (1/\mathrm{T})] \times 100\% \tag{2}$$

Where, LU_i is the size of land use of Type i at the beginning of the period of the region under research; $\triangle LU_{i-j}$ is the absolute value of the size of land use of Type i being converted into land use of a type other than Type i; and T represents the length