Managing Beijing's Water Resources with Payment for Environmental Services

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Abstract In response to environmental threats to its primary water source, Beijing recently implemented new environmental management programs in the catchment of the Miyun Reservoir. Despite some success at addressing its deteriorating water quality, the Miyun remains vulnerable to excessive nutrient runoff and risks realizing the same deteriorated fate as Beijing's previous water source, the Guanting Reservoir. The payment for environmental services (PES) model may represent a promising approach to addressing non-point source pollution in the Miyun. By aligning economic activities with environmental goals and increasing coordination between upstream and downstream communities, PES can address some of the key weaknesses in the Miyun's current management program. Based on quantitative analysis, this paper finds that fertilizer reductions are a strong candidate for a PES scheme in the Miyun, although additional hydrological research to develop precise cost and benefit impacts is needed. China's experience with the PES model illustrates some of its challenges, as well as providing lessons for its future application.

Introduction

Beijing's Water Challenges Beijing faces the most complex and urgent water problems of any city in China. Beijing is located in the Haihe River Basin, a river system in the upper half of China's North Plain. The basin averages only 305 m^3 of fresh water per capita – 5% of the world average and far below the 1000 m^3 per capita threshold used by water experts to define water scarcity (Xia et al., 2006). Low rainfall level (under 550mm annually) must be shared by over 118 million residents of the Haihe basin, making the Haihe the most water deficient of all of China's major river basins (Domagalski *et al.* 2001).

Recognizing the importance of water to the long-term prosperity of Beijing, China's leadership focused on both reducing Beijing's water demand and increasing its water supply. Between 1950 and 1990, Beijing averaged water use increased by more than 4% annually. Beginning in the early-1990s, Beijing effectively managed its water and actually reduced its annual water use between 1995 and 2005, according to official estimates, despite both rapid GDP and population growth during this period (Beijing Statistical Yearbook, 2006). Although Beijing's total water usage has decreased in recent years, the city continues to face annual water deficits of .3 – 1.5 billion cubic meters (Hou and Hunter, 1998).

Located 100 km northeast of Beijing, the Guanting Reservoir was constructed in 1952 to serve as the primary water source for the city (Enders, 2005). Pollution rapidly accumulated in the Guanting during the 1960s and 1970s, stemming from industrial, mining and agricultural activity located in the upstream parts of Guanting's catchment area (Peisert and Sternfeld, 2005). During the 1970s, China established environmental protective zones to protect the Guanting. However, the program was never fully implemented due to lack of financing and agreement among the different parties involved.

By the mid-1980s, the Guanting's waters had become so heavily polluted that Beijing was forced to find new water sources.[1] The nearby Miyun Reservoir was used to supplement its water supply. This reservoir had served the coastal city of Tianjin, located to the southeast of Beijing, forcing Tianjin to find new water resources in nearby waterways (Eva Sternfeld, personal communication, 2007). By the time Beijing began using the Miyun Reservoir as its primary

[1] Pollution levels in the Guating were further aggravated by consecutive drought years, which caused pollution concentration levels to increase (Sternfeld, personal communication).

water source, the Guanting had deteriorated to class 5 water quality, limiting it use to only industrial purposes (Sternfeld and Peisert, 2005).

Without access to the Guanting reservoir, the Miyun became Beijing's primary water source, providing 1.5 million cubic meters of water each day to city water users. The Miyun was fortunate enough to not deteriorate to the same water quality as the Guanting mainly because lack of development in the Miyun's upper catchment. Originally built to mitigate flooding and provide clean water to Tianjin and rural areas near Beijing, the Miyun reservoir has since evolved to service the needs of Beijing almost exclusively**,** providing half of Beijing's water needs in normal rainfall years.

MANAGING THE MIYUN The Miyun Reservoir is regarded as one of the most important water protection areas in the world (Sternfeld and Peisert, 2005). Lacking major auxiliary water sources, Beijing would be vulnerable to an environmental catastrophe that might reduce the capacity or quality of the Miyun, leaving one of China's most important cities waterless. Currently, the biggest threat facing the Miyun is excess pollution from upstream economic activity – the same threat that overwhelmed the Guanting. Since 2000, the water has degraded from class II to class III (Enders, 2005). The Miyun is currently in a mesotrophic state[2] due to moderate levels of nutrient concentrations in the reservoir (Wang et al., 2001). Among the chief causes of high nutrient loads in the Miyun is excess fertilizer application in the catchment area. Scientist generally regard any lake or reservoir with a ratio over 16:1 to be phosphorus limited, suggesting that phosphorus is by far the key limiting nutrient in the Miyun (Mason, 1996). The nitrogen to phosphorus level in the Miyun has been measured at over 38:1. If left unmitigated, pollution increases could lead the Miyun to the same fate as its predecessor.

In the face of these risks, Beijing adopted new environmental programs aimed at reducing the pollution accumulation in the Miyun. During the mid-1990s, the Beijing government established three "environmental protective zones" around the Miyun Reservoir. The innermost zone, covering the land located within approximately 300 meters of the reservoir restricts all agricultural and residential activities (see Figure 1). The second zone allows limited agricultural activity, while the third and outermost zone limits mining and industrial activity (Peisert, personal communication, 2007).

[2] Mesotrophic lakes have heightened levels of nutrients and will usually turn eutrophic in the future. Although they are not eutrophic, they are vulnerable to experiencing periodic eutrophic events.

Figure 1. Sign at the boundary of the Miyun's Reservoir's innermost protective zone. "It is the responsibility of everyone to protect our water resources"

These zones represent a welcome departure from China's traditional approach to resource management. Historically, China responded to natural resource problems by building large-scale, elaborate infrastructure projects – such as the sophisticated levee system on the Yellow River or the Three Gorges Dams on the Yangtze River. These 'supply' solutions rarely addressed the policy and management issues that are key to creating sustainable, long-term solutions to managing natural resources.

The Miyun's environmental protection zones have been moderately effective at reducing the most overt and extreme pollution sources (Peisert, personal communication, July 2007). However, the zones largely fail to address the causes of subtler forms of pollution. While point source pollution has been effectively regulated and removed from the watershed, non-point source pollution - primarily in the form of agricultural runoff - continues to contaminate the Miyun's water (Wang et al., 2001). In 1985, non-point source pollution accounted for 53% of the total phosphorus entering the Miyun. More recently, such pollution accounts for 94% of Miyun pollution (Wang et al., 2006).

Lack of enforcement in the protective zones and poor coordination across jurisdictional boundaries contribute to the mediocre impact of the protective zones. During July 2007, agricultural activities continued unabated throughout the innermost protective zone of the Miyun, despite the farming ban (see Figure 2).

Figure 2. A farmer tends crops inside the first protective zone on the banks of the Miyun (July 2007).

Like the protective zones in the Guanting, coordination between different jurisdictions in the Miyun remains weak, limiting the effectiveness of the zones. The current protective zones only cover the lower one-third of the watershed – the area that falls under the Beijing prefecture's control. The upper two-thirds of the catchment is located in the Hebei province (see Figure 3). Beijing and Hebei dispute water rights and pollution responsibilities in the Miyun watershed, limiting opportunities to establish comprehensive strategies for managing the Miyun catchment (Sternfeld and Peisert, 2005).

Figure 3. Map of the Miyun Reservoir Catchment

Upstream versus Downstream The lack of management coordination in the Miyun is emblematic of the management problems facing water resources throughout China. Poor management coordination in China is primarily due to two factors: jurisdictional disputes between different provincial governments over water rights and competing development priorities between upstream and downstream communities.

Poor watershed coordination results in inefficient water supply distribution between upstream and downstream communities. Traditional water allocations favored farming interests, often providing them with first priority to limited water resources at almost no cost. Upstream farmers and factories use large quantities of water, leaving low river flow for downstream communities. As a result, downstream areas must contend with low water quantity and quality. Urban communities struggle to access adequate water supplies and often must pay much higher prices for water. Reduced downstream flow threatens ecological conditions in downstream areas.

Underlying these coordination problems is a growing economic rift between rural upstream communities and urban downstream communities in China. Downstream communities have largely benefited from the past half-century of rapid economic growth, while upstream areas have not. Rural upstream areas of China remain poor, primarily relying on traditional agriculture practices and manufacturing jobs to sustain themselves. The average income in rural areas is only one-sixth that of urban areas when considering subsidies only urban residents receive (Dong et al 2006).

These factors contribute to the management challenges in the Miyun watershed. Managing water resources in the Miyun involves reconciling the competing and often contradictory needs of two groups – upstream Miyun farmers and downstream urban water users. Both groups are focused on getting more resources to support increasing economic growth and find themselves competing for limited water resources. Fueling the water needs of the rural farmers in the Miyun is their desire to experience the same economic growth that has fueled the increasing standard of living in Beijing. While environmental regulations in Miyun are designed to protect water for downstream users, these regulations act to stifle economic growth for Miyun farmers by restricting farming in protected zones and limiting certain crops in the second protected zones.

A sustainable solution to the managing the Miyun must incorporate new approaches to reconciling the needs of both upstream and downstream communities. Beijing should develop environmental regulations that protect its water source, while also recognizing the economic needs of upstream communities. The question remaining is how to coordinate these competing interests and develop a long-term, sustainable solution to managing the Miyun watershed

New Approach: Payment for Environmental Services The payment for environmental services (PES) management program is a relatively new watershed management model tool that has the potential to reconcile competing stakeholders interests, as well as providing stronger incentives for upstream communities to protect critical water sources. Under a PES agreement, upstream communities receive economic incentives to provide environmental services that are valuable to downstream areas. Downstream communities pay for these services in an amount that reflects the value they derive from these services.

Traditional environmental regulations incorporate a 'polluter pays' approach to managing environmental resources. This method is widely popular because it appeals to a universal sentiment that those who create pollution should bear the responsibility and cost of cleaning it up. The 'polluter pays' model essentially assigns the right to a water body or a resource as belonging to downstream communities. Pollution is viewed as a 'negative externality' that should be incorporated in to the costs facing polluters. These environmental regulations typically incorporate a threshold for determining compliance.

By establishing a financial relationship between the providers of environmental services and their beneficiaries, a PES system harnesses market forces to improve the efficiency of environmental mitigation and ensure strong enforcement. PES gives downstream users an incentive to monitor the environmental services they are purchasing. PES can provide an incentive for upstream communities to identify and reduce upstream pollution sources. This approach often results in solutions closer to the problem source, resulting in lower mitigation costs. These communities can target mitigation opportunities that are lowest in cost, rather than adhering to rigid universal standards.

The identification of program beneficiaries helps PES support sustainable, long-term financing and enforcement. While many environmental programs face the constant risk of losing funding as government revenue fluctuates, PES schemes ensure stable enforcement funding as long as it is economically justifiable to generate environmental services.

PES can also serve as an effective development tool that aligns economic development with environmental goals. In many parts of the world, upstream areas are remote from economic and population centers. Many of these areas are the target of economic development programs aiming to improve the livelihood of these communities. Payments to upstream communities can provide jobs or social services to economically depressed communities, while simultaneously serving the environmental needs of the broader ecological area.

Watersheds serving as drinking water sources for urban populations provide particularly strong opportunities to use the PES model. Land use and ecological services often have a critical impact on the quality of water bodies. A variety of ecological services can serve to reduce the buildup of pollutants in river, reservoirs, and lakes. Ecological services in these reservoirs benefit a distinct group of beneficiaries – downstream residential communities. Downstream water users are represented by a single entity that can capture the entirety of the benefits from watershed management improvements. What would normally be dispersed positive externalities can be internalized in the cost facing municipal water treatment organizations.

We hypothesize a Payment for Environmental Service program within this watershed can reconcile the contending interests between the downstream community and the upstream farmers.

Methods

Study Site The Miyun reservoir is located 70km north of Beijing, China. It has a total area of approximately 14,871 square kilometers, providing over 1.5 million cubic meters of water a day to Beijing (see table 1). The Chinese Academy of Sciences – Key Ecosystems Laboratory provided lab space while conducting the research in China. Internet access, drivers to and from the Miyun Catchment, translators and data hard to find in English were provided by the lab.

Our PES model was based upon Stefano Pagiola's basic framework regarding a successful payment for environmental service (see figure 4). Both Miyun farmers and Beijing will want to participate in this relationship if the net benefits to both upstream and downstream users is greater in a PES scheme than with the current status quo. The reduction in the net costs - the cost associated with treating polluted water - is associated with a reduction in nutrient runoff. The total savings to Beijing is the max payment to compensate upstream farmers for providing this service, cleaner water.

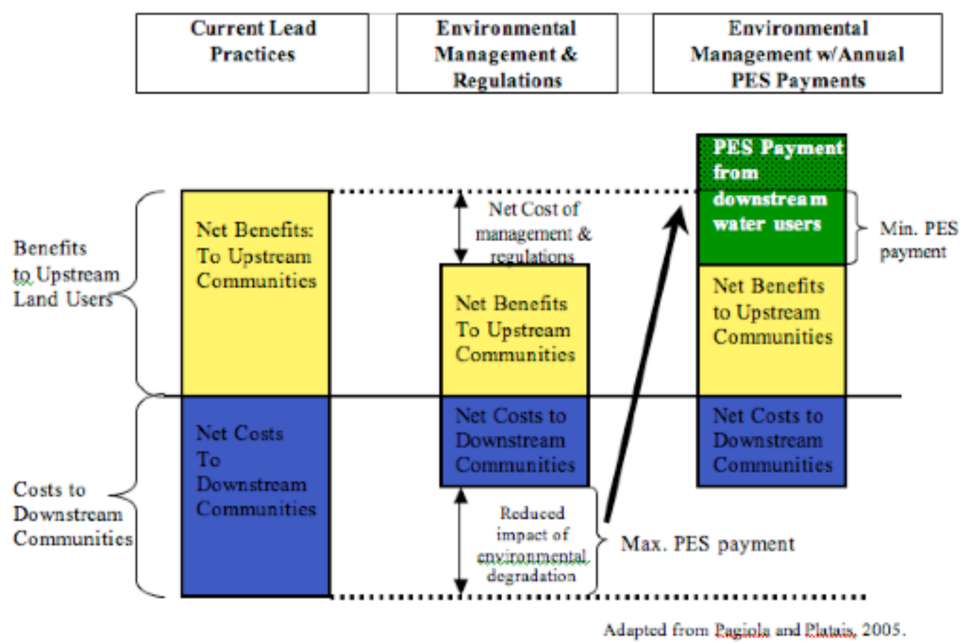

Figure 4. Chart is adapted from the work of Stefano Pagiola and conveys how a successful PES reduces environmental degradation, minimizing costs to downstream communities & maximizing benefits to upstream users

Basic hydrological relationships and data characteristics (see Table 1) of the Miyun catchment were used to develop a model estimating the impact of sustained fertilizer reductions over a ten-year period .

Table 1: Data Characteristics of the Miyun Reservoir

Characteristics of Miyun Watershed Catchment	
Total Catchment Area	15,800 km2
Total Population	144,000
Total hectares of cropland	237,000
Average Income per household (US$)	341
Average income per cropland hectare (US$)	775
Estimated Phosphorus Concentration in Miyun Reservoir [mg/L]	0.031
Average Phosphorus Fertilizer Application per hectare (US$)	$26
Fertilizer efficiency rate	50%
Drinking water production (m^3 per day)	1,500,000
Average Monthly Treatment Cost (US$)	11,600,000

Pyke and Becker (2004) analyzed several research projects that attempt to estimate the impact of water quality on water treatment costs. These studies were averaged to provide a linear relationship between percent in treatment cost and increased levels of total organic carbon (TOC) in a water body.

$$\text{(percent change in TOC)} = .3756\ \text{(percent change in water treatment costs)}$$

Pyke and Becker (2004) provide an equation estimating the relationship between TOC and total phosphorus (TP) levels in a water body:

$$[\text{TOC (mg)/L}] = (.56)\ [\text{TP (ug)/L}]^{.63}$$

Crop runoff is estimated to account for 25% of the surface runoff in the Miyun catchment, despite that fact that agriculture accounts for only 15% of the land in the Miyun (Guo et al., 2004). The following equation is used to estimate the impact of a sustained change in surface runoff concentrations on reservoir concentrations over time. This equation is based on the work of Vollenweider (1968) and other researchers who have attempted to develop simplified relationships between nutrient runoff in a watershed and nutrient load in a water body. Similar models were utilized by Wang (2005) Chen (1998) and in previous research on Miyun water quality.

$$P_{(t+1)} = (e_{-.7(t+1)})(L_p)/(F_{out}/V) + P_t$$

Where:

t = time in years

Fout = Flow out from Miyun Reservoir

V = volume

L_p = "normalized" phosphorus runoff load (grams per sq. meter of reservoir surface)

P_t = average annual phosphorus concentration in the Miyun at the beginning of year t

$P_{(t+1)}$ = average annual phosphorus concentration in the Miyun one year after year t

This equation yields the annual phosphorus concentration in the Miyun over time, given a one-time, permanent change in the phosphorus runoff load. Flow in and flow out are assumed to be equal, yielding a constant volume in the Miyun[4]. This model assumes that 20% of fertilizer is taken up by plants and that of the remaining fertilizer, 80% runs off to surface water bodies in the catchment. Evaporation levels and ground leaching are treated as zero – phosphorus strongly bonds to soil and resists losses through these processes (Mason, 1996). This model assumes that fertilizer reductions applied to all users in the Miyun and that all of them comply with the reduction requirement. Fertilizer reductions are assumed to result in a 1:1 reduction in crop revenue, a very conservative estimate, given the reports that farmers in the region are over-fertilizing their cropland[5]. To minimize crop loss from fertilizer reductions, we looked at a case study in Minnesota to provide an estimated cost for implementing a fertilizer efficiency program. A fertilizer efficiency program aims to improve the crops uptake of chemical nutrients by educating farmers how to implement better management practices. The result is better crop yields with less fertilizer. Reducing fertilizer application, combined with a fertilizer efficiency program, is analyzed with the model. The model evaluated fertilizer reductions ranging from 10%-50%.

[4] Assumes that flow in equals flow out. This would yield a constant volume over time, which is also assumed in this model. The simplified model should be further analyzed with hydrological studies to reaffirm this assumption.
[5] Zhang et al (2003) found that subsidies could be used to reduce fertilizer applications without incurring large crop losses in the Taihu watershed.

Results

According to these parameters, general fertilizer reductions can reduce phosphorus concentrations in the Miyun, but only at a high cost in crop revenue losses. Annual costs to upstream users range from 140 to 680 million USD, while benefits to downstream users only reach a maximum of 40 million USD annually. A fertilizer efficiency program could be incorporated into a PES scheme to reduce the impact of crop losses from fertilizer reductions. Using research from a fertilizer efficiency program conducted in the Sand Creek Watershed in Minnesota (USA), fertilizer efficiency could be increased by 40% at a cost of $6-9 per hectare (Robert Johansson et al., 2004)[6]. Assuming that a fertilizer efficiency program is instituted as part of a PES system, crop revenue losses will decrease for each level of fertilizer reductions. Costs for upstream individuals will now include the cost of the fertilizer efficiency program.

Incorporating a fertilizer efficiency program allows both parties to experience net benefits under a PES scheme for fertilizer reductions in the Miyun (see Fig 5). Target abatement levels up to 40% correspond with benefits to downstream users that exceed costs to upstream farmers. At 50% fertilizer reductions, costs to upstream farmers exceed the net benefits downstream users gain from improved water quality. The net benefit to downstream communities represents the maximum they would be willing to pay for fertilizer reductions. On a per hectare of cropland basis, net present benefits equal $38, $58, $78, $98 at each respective fertilizer reduction. At these rates, payments could be set at an estimated maximum of $3, $4, $6 and $7 for households with .57 hectares of cropland, estimated as the average land holding in the Miyun (Yuan, 2007).

[6] While the cost of labor for these programs is less expensive in China, this cost reduction would likely be partially offset by the increased cost of getting specialized experts to teach and manage the program. Differences in the fertilizer application methods (mechanization vs. hand applied) will also differ between the case studies and needs further research. Overall though, the cost of executing a similar program in China is likely less expensive than the U.S. example, but this paper assumes the maximum in the cost range ($9) provided by Johanson (2004) to be conservative.

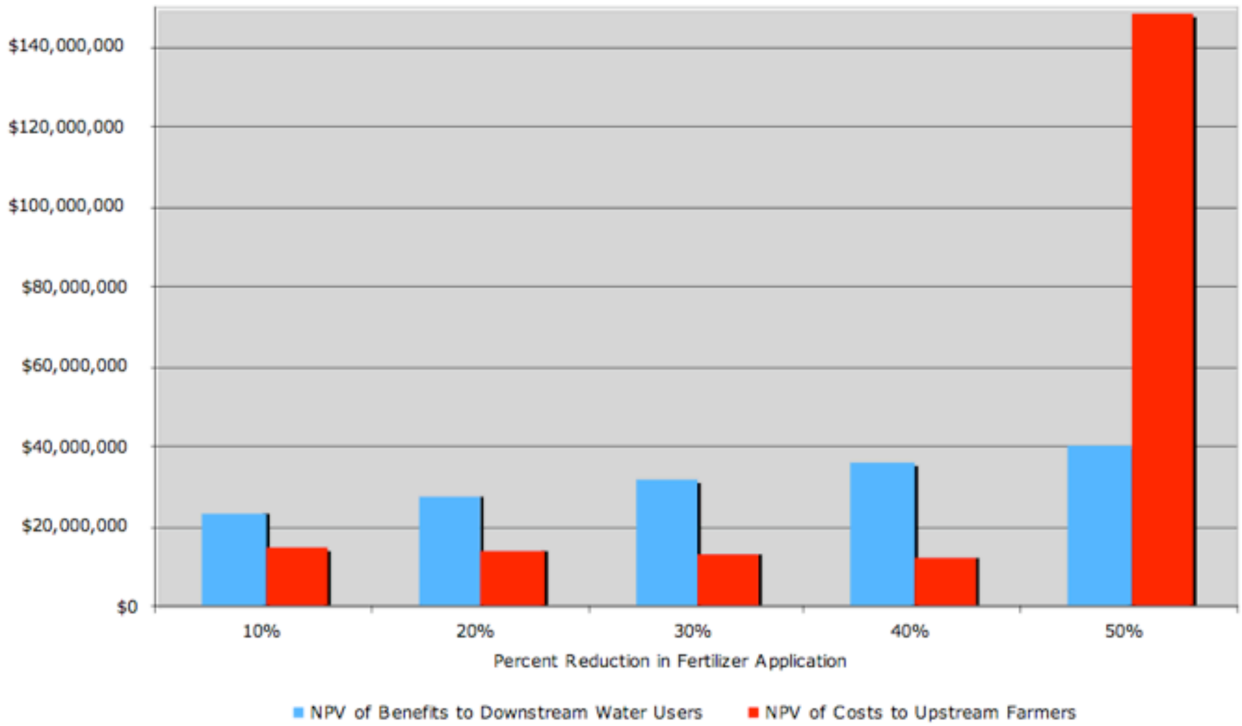

Figure 5. The benefits to downstream water users and the costs to upstream farmers is graphed based upon the percent reduction in fertilizer application, from 10% to 50%. Benefits for downstream users is shown to exceed costs to upstream farmers up until 40% abatement, but at 50% reduction costs far exceed net benefits.

These estimate do not include administrative expenses. Both upstream and downstream parties will likely need to support committees to monitor payments and activities. Assuming administrative expenses are equal to 20% of the program implementation cost, the PES system yields net benefits under the fertilizer efficiency scenario (see figure 6). On a per hectare basis, net benefits are $25, $46, $66 and $87 for fertilizer reductions of 10%, 20%, 30% and 40%, respectively (see figure 7). At these levels, households with the average land holding would receive $2, $3, $5, and $6 at each of the respective fertilizer reduction levels.

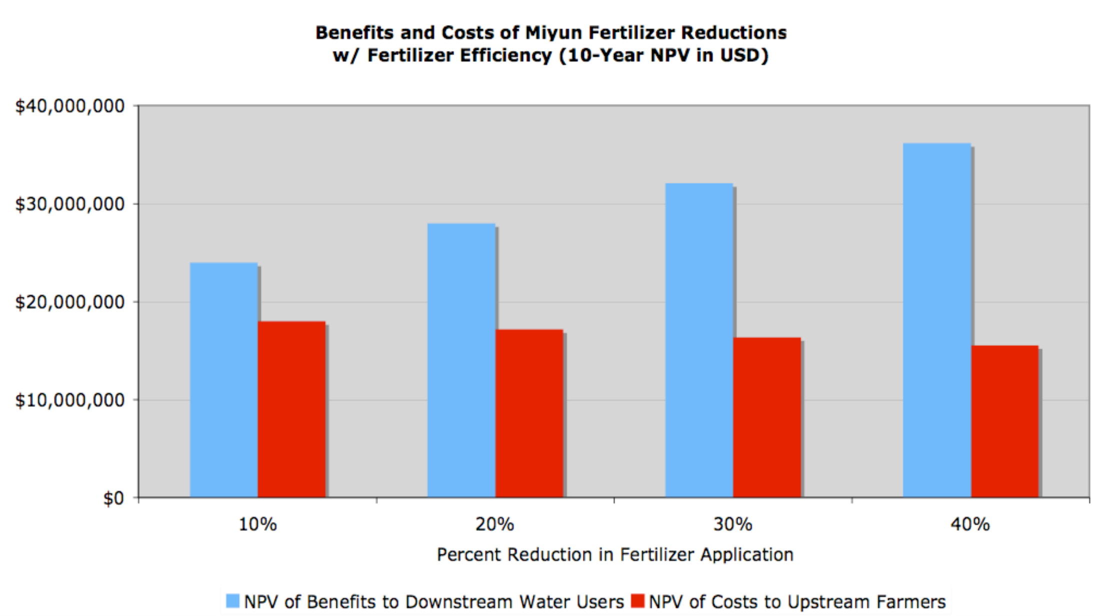

Figure 6. When incorporating a fertilizer efficiency program, the benefits and costs of Miyun fertilizer reductions were graphed at each abatement level up to 40%. Net benefits for downstream users exceeds the costs to upstream farmers associated with these reductions. Costs are decreasing as more fertilizer is abated due to the reduction in fertilizer costs.

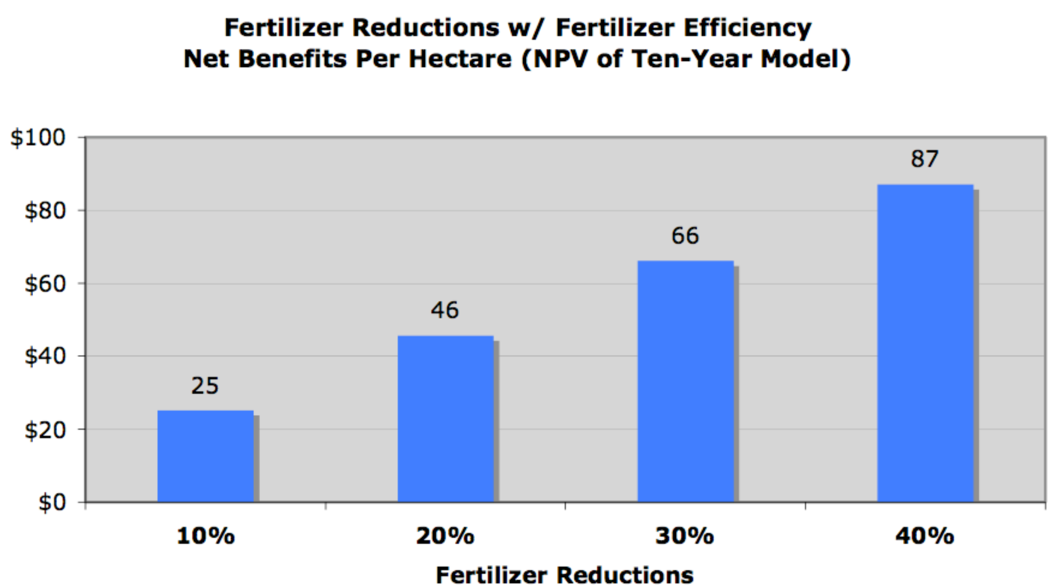

Figure 7. The estimated net benefits from PES fertilizer reductions (with a fertilizer efficiency program) are graphed to convey an increasing benefit to Miyun farmers at each increase in fertilizer reduction, from 10 to 40%. Administrative expenses are incorporated in this graph.

At the 30% and 40% level, the willingness to pay of downstream users exceeds the minimum payment needed for farmers upstream. Farmers maximize their net income at a 40% abatement level because benefits to downstream users is maximized (see figure 6), thus increasing the payment to upstream users. Fertilizer costs are also reduced at each higher abatement level because less fertilizer is purchased by farmers.

Discussion

Fertilizer reductions appear to be an ideal case for a PES system, as excess fertilizer use is the primary cause of high nutrient loads in the Miyun. Given the failure of traditional regulatory methods, economic incentives may be effective at encouraging farmers to adjust the farm activities that impact water resources. With no system in place to monitor agricultural runoff from individual farms, ineffective farming practices such as excessive fertilizer use go unchecked in the Miyun catchment. Using positive economic incentives under a PES will motivate upstream Miyun farmers to identify and reduce upstream pollution sources. Self-regulation under a PES will provide solutions closer to the problem and be more cost effective.

The results of this model should be applied with caution, as numerous simplifications were applied. Variations in weather conditions could significantly increase or reduce the monthly nutrient loads entering the Miyun. A catchment-wide payment system would generate large inefficiencies, as fertilizer reductions from farmers located far from water bodies contribute substantially lower nutrient loads to the Miyun Reservoir. Specific analysis of the water treatment procedures used at the Miyun would provide more accurate cost estimates.

Despite necessary simplifications, modeling fertilizer reductions in the Miyun catchment suggests that there is an opportunity to use a PES system to support fertilizer reductions that can be financially beneficial for both upstream and downstream communities. Ecohydrological research on the Miyun can identify specific areas that are particularly vulnerable to erosion, allowing upstream communities to better target their effort at reducing agriculture runoff. Access to more sophisticated hydrological research on the Miyun could provide greater insight into the benefits and costs associated with upstream activities in the Miyun.

Setting a price near the maximum willingness to pay of downstream entities could better serve the development needs of upstream communities. Using the higher target level (40%) in the PES scheme would result in a net increase in income for upstream farmers, allowing these

Miyun communities to address some of their development needs – such as improved education services, more efficient agricultural technology (drip irrigation systems), providing capital toward developing environmentally-friendly industries, or serving to increase household consumption.

Challenges for PES in China While PES involves market-based ecological services transactions, oversight from local government agencies is important to establish enforceable agreements between parties. Government involvement is helpful in addressing three issues: limiting opportunities for upstream or downstream parties to abuse one another, increasing coordination between jurisdictions, and addressing some of the high up-front costs associated with establishing new institutions and PES services. Government intervention is helpful to establishing agreements, however excessive government control can serve to weaken the user-beneficiary link.

Small PES projects can face high transaction costs in the form of monitoring environmental outcomes, negotiating agreements and managing program activities. The cost of these activities should be included in the program's financial assessment and carefully assigned to avoid future conflict over the cost of program management.

PES systems can provide payments to upstream communities or to upstream individuals directly, providing positive economic incentives for self regulation. Paying individuals can result in the highest economic efficiency, because it ensures that only individuals who can provide environmental services at a low cost will participate. However, establishing contracts with each individual household results in high transaction costs. Some of these transaction costs can be avoided by paying communities, although payment to communities may result in compulsory participations from households who will incur high costs, such as high crop losses. Community payments may help encourage greater compliance in upstream communities by creating social pressure on farmers to comply.

Despite its many advantages, payment for environmental services faces the challenge of linking benefits to ecological services. Simplified relationships between the cause of non-point source pollution and its impact are difficult to establish, as ecohydrology provides few easy answers to understanding the link between land use, runoff and water contamination. Non-point source pollutants often have complex transport flows involving numerous land and environmental characteristics. A range of factors affect the concentration of agricultural pollutants in a water body and these factors are often unique to each water body. Accordingly, it can be difficult to assign monetary values to ecological services. Additional ecohydrologic studies are necessary to determine the actual impact of water quality from different areas and land uses. Modeling fertilizer reductions suggests that there is an opportunity to use a PES scheme for reductions that could be financially beneficial for both upstream and downstream communities. However, complex hydrological relationships require the use of sophisticated modeling techniques to determine more precise relationships between upstream activities and Miyun water quality. The use of hydrological models may reveal specific areas that are particularly vulnerable to erosion, allowing upstream communities to better target their effort at reducing agriculture runoff.

The Miyun still presents a strong opportunity to establish a local PES scheme that meets the development needs of rural upstream residents and the water needs of urban downstream communities in the Beijing Municipality. With 144,000 residents within the catchment and over 20 million residents in Beijing, the successful implementation of a payment for environmental service will better serve both downstream and upstream water users and protect one of China's most crucial water sources from eutrophication.

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REFERENCES

Beijing Statistical Yearbook, 2006. Accessed through http://www.chinadataonline.org.

Bennett, M., Xu, J., 2004. China's Sloping Land Conversion Program: Institutional Innovation or Business as Usual?, Chinese Center for Agricultural Policy (2004): 1-25.

Carpenter, S.R., Ludwig, D., Brock, W.A., 1999. Management of eutrophication for lakes subject to potentially irreversible change. *Ecological Applications*, Vol. 9, No. 3.

Chen, Y., Zhang, B., Ju, Y., 1998, "Analysis and Prediction of Eutrophication for Miyun Reservoir." Shuili Xuebao, July.

Dai, X. X., Peng, S., Xie, G. H., Steinberger, Y., 2006. Water Use and Nitrate Nitrogen Changes in Intensive Farmlands Following Introduction of Poplar in a Semi-Arid Region. Arid Land Research and Management, 20:4, 281-294.

Domagalski, J., Xinquan, Z., Chao, L., Deguo, Z., Chi, F.L., Kaitai, X., Ying, L., Yang, L., Shide, L., Dewen, L., Yong, G., Qi, T., Jing, L., Weidong, Yu., Shedlock, R., Knifong, D., 2001. Comparative water-quality assessment of the Hai He River basin in the People's Republic of China and three similar basins in the United States. USGS, Professional Paper No. 1647

Dong, Xiao-yuan, Shunfeng Song and Xiaobo Zhang, eds. (2006) *China's Agricultural Development: Challenges and Prospects*. Aldershot: Ashgate.

Enders, S., 2005. Miyun: Integrated Watershed Management for the Protection of Beijing's Drinking Water. http://forestry.msu.edu/China/New%20Folder/S.Enders-Miyun.pdf.

Erickson, J. D., Limburg, K., Gowdy, J., Stainbrook, K., Nowosielski, A., Hermans, C., Polimeni, J., 2005. An Ecological Economic Model for Integrated Scenario Analysis: Anticipating Change in the Hudson River Watershed, in: Economics and Ecological Risk Assessment: Applications to Watershed Management. Randall J.F. Bruins (Ed.), Boca Raton, FL: CRC Press.

Guo, H.C., Zhang Z.X., Yu, Y., 2004. A Grey Multi-Objective Programming Approach for Sustainable Land-Us in the Miyun Reservoir Basin, China. Journal of Environmental Sciences, Vol. 16, No. 1, pp.120-125.

Johansson, R., Gowda, P., Mulla, D., Dalzell, B., 2004. Metamodeling phosphorus best management practices for policy use: a frontier approach. Agricultural Economics, 30, p.63-74.

Jun, H., 2006. Payment for Environmental Services in China: A Policy Perspective. ICIMOD Newsletter, Summer 2006, World Agroforestry Centre (ICRAF, China).

Langton, A., 2006. Achieving Sustainable Groundwater Management in the North China Plain. http://bigideas.berkeley/node/39.

Liu, Y., 2007. Phosphorus Use in China. in: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington D.C.: Environmental Information Coalition, National Council for Science and the Environment). Peter Hughes and Sohail Murad (Eds.) [Published in the Encyclopedia of Earth April 4, 2007; http://www.eoearth.org/article/Phosphorus_use_in_China. Retrieved Dec. 10, 2007].

Ma, X., Ortolano, L., 2000. Environmental Regulation in China: institutions, enforcement and compliance. Rowman & Littlefield, Lanham, Maryland.

Mason, C.F. 1996. Biology of Freshwater Pollution. Longman Group Limited, London.

Pagiola, S. 2003. The Importance of Forest Protected Areas to Drinking Water: Running Pure. World Bank/WWF Alliance for Forest Conservation and Sustainable Use. Washington, DC.

Pagiola, S., Arcenas, A., Platais, G., 2005. Can Payment for Environmental Services Help Reduce Poverty? An Exploration of the Issues and the Evidence to Date from Latin America, World Development, Vol. 33 (2), pages 237-253.

Peisert, C., Sternfeld, E., 2005. Quenching Beijing's Thrist: The Need for Integrated Management for the Endangered Miyun Reservoir. China Environment Series, Issue 7.

Postel, S.L., Thompson, B.H.Jr., 2005. Watershed Protection: Capturing the Benefits of Nature's Water Supply Services. Natural Resources Forum 29, 98-108.

Pyke, G.W., Becker, W., 2004.Impacts of Major Point and Non-Point Sources on Raw Water Treatability. Water Intelligence Online (Vol. 3, September 2004).

Qiao, F., Lohmar, B., Huang, J., Rozelle, S., Zhang, L.X., 2003. Producer Benefits From Input Market and Trade Liberalization: The Case of Fertilizer in China. American Journal of Agricultural Economics 85:5, 1223-1227.

Rast, W., Jones, R.A., Lee, G.F., 1983. Predictive Capability of U.S. OECD Phosphorus Loading Eutrophication Response Models. Water Quality Volume 55, Number 7. <http://www.members.aol.com/annelhome/PredictiveCapabilityOECD.pdf>.

Robinson, L.W., Venema, H.D., 2006. Perspectives on Watershed-Based Payments for Ecosystem Services. International Institute for Sustainable Development.

Rosa, H., Kandel, S., Dimas, L., 2003. Compensation for Environmental Services and Rural Communities: Lessons from the Americas and Key Issues for Strengthening Community Strategies. International Forestry Review, 6:2. P. 187-194.

Reuters, 2007. "Algae Outbreak in China Threatens Water Supplies." July 18, 2007. <http://www.reuters.com/article/healthNews/idUSPEK15919320070718>.

Vollenweider, R.A.,, 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Pub. No. DAS/SAI/68.27, Organization for Economic Cooperation and Development, Directorate for Scientific Affairs. Paris.

Wang J., Cheng S., Jia, H., 2005. Water Quality Changing Trends of the Miyun Reservoir. Journal of Southeast University, June 2005, Vol. 21, No. 2.

Wang, X., Li, T., Xu, Q., He, W., 2001. Study of the distribution of non-point source pollution in the watershed of the Miyun Reservoir. Water Science and Technology, Vol. 44 No. 7.

Wang, X., Wang Y., Li, T., He, W., Hu, Q., Zhang, H., 2002. Characteristics of Non-Point Source Pollution in the Watershed of Miyun Reservoir. Chinese Journal of Geochemistry, Vol., 21, No. 1.

Wang, Xiaoyan, Wang, Xiaofeng, Wang, Z., Wang, Q., Cai, X., 2003. Nutrient Loss from Various Land-Use Areas in Shixia Small Watershed of Miyun County, Beijing China. Chinese Journal of Geochemistry, Vol. 22 No. 2.

Wang, X., Cao, L., 2006. Economic Approach to the Control of Agricultural Non-Pint Source Pollution in China – A Case Study of the Miyun Reservoir in Beijing. Journal of Ecology and Rural Environment, 22 (2): 88-91 (in Chinese).

Weyerhaeuser, H., and Kahrl, F., 2005. An Enduring Match? Livelihoods, Conservation and Payments for Environmental Services in the Uplands of China's Southwest. Conference on International Agricultural Research for Development.

Wolf, J. et al., 2003. Urban and Peri-urban Agricultural Production in Beijing Municipality and its Impact on Water Quality. Environment and Urbanization 2003, 15:141.

Wu J.J., and Babcock, B.A., 1996. Contract Design for the Purchase of Environmental Goods from Agriculture. American Journal of Agricultural Economics, Vol. 78, No. 4.

Xia, J., Feng, H.L., Zhan, C.S., Cun-Wen, N., 2006. Determination of a Reasonable Percentage for Ecological Water-Use in the Haihe River Basin, China. Soil Society of China. 16(1): pages 33-42.

Xu, Q., Yanf, T.X., Liu, X., Ge, X.L., 2003. Analysis and Prediction of Eutrophication for Miyun Reservoir. Journal of Jilin University (Earth Science Edition). (in Chinese).

Young, T.F., Karkoski. J., 2000. Green evolution: Are economic incentives the next step in nonpoint source pollution control?, *Water Policy*, **2**(3), pp. 151-173.

Yuan, Z., Zhang, Y., Abbaspour, K.C.A., Mosler, H.J., Yang, H., 2007. Modeling the Impacts of Up- and Downstream Water Reallocation on Rural Communities and Social Equity in the

Chaobai Watershed in China. Institute of Geographic Sciences and Natural Resources Research, Chinese Academic Sciences.

Zhang, W., Shi, M., Huang, Z., 2006. Controlling Non-Point Source Pollution by Rural Resource Recycling. Nitrogen Runoff in Tai Lake Valley, China, as an Example. Sustainable Science (2006), 1:83-89.

Zheng, H., Qin, T., 2007. Payments for Environmental Services in the Miyun Reservoir Basin, China. Published as part of the international conference on "Economic Transition and Natural Resource Management in East and Southeast Asia," Ho Chi Minh City, Vietnam, June 21-22, 2007.