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Discussions

Relationships between environmental governance and water quality in growing metropolitan areas: a synthetic view through the coupled natural and human system lens

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Abstract

We investigate relationships between environmental governance and water quality in two adjacent, growing metropolitan areas in the western US. While the Portland, Oregon and Vancouver, Washington metro areas share many biophysical characteristics, they have different land development histories and water governance structures, providing a unique opportunity for examining a coupled human and natural system (CHANS). We conceptualize feedback loops in which water quality influences governance directly, using monitoring efforts as a metric, and indirectly, using the metric of changes in the sale price of single-family residential properties. Governance then influences water quality directly through, for example, changes in the monitoring regime and riparian restoration and indirectly through land use policy. We investigate these hypotheses by presenting evidence of these linkages. Our results show that changes in monitoring regimes and land use differed in response to differences in governance systems. On the other hand, property sale prices increased in response to water quality improvement for both studied watersheds. Our results show that sales prices responded positively to improved water quality (i.e. DO) in both cities. Furthermore, riparian restoration efforts improved over time for both cities, indicating the positive effect of governance on this land-based resource that may result in improved water quality. However, as of yet, there were no substantial differences across study areas in changes in water temperature over time. While urban areas expanded more than 20 % over 24 yr, water temperature did not change. The mechanisms by which water quality was maintained was similar in the sense that both cities benefited from riparian restoration, but different in the sense that Portland benefitted indirectly from land use policy. A combination of a long-term legacy effect of land development and a relatively short history of riparian restoration in both the Portland and Vancouver regions may have masked any subtle differences in both regions. An alternative explanation is that both cities exhibited combinations of positive indirect and direct water quality governance that resulted in maintenance of water quality in the face of increased urban growth. These

findings suggest that a long-term water quality monitoring effort is needed to identify the effectiveness of alternative land development and water governance policies.

1 Introduction

The dynamic relationship between environmental quality and local governance is increasingly conceptualized through a coupled human and natural systems (CHANS) approach (Liu et al., 2007; McConnell et al., 2011). While this approach holds promise for understanding dynamic relationships over time, an important theoretical and empirical question is through what pathways and to what extent biophysical systems and human or social systems are coupled. Empirical observation and theoretical conceptualization are needed to begin to understand the processes and feedbacks that link these systems.

This study considers multiple pathways by asking how scientific knowledge and human perceptions about local water quality enter the policy process and how policy actions in turn affect local water quality over time in urban areas. We consider two pathways by which water quality information and perception of water quality might enter the human system: water quality monitoring and the sale price of single-family residential properties. We consider riparian corridor restoration projects and land use policy as government actions that might impact water quality.

We investigate interactions between water quality and environmental governance in a single metropolitan area with bifurcated governance. In the Portland–Vancouver metropolitan area in the Pacific Northwest of the United States, a common biophysical landscape spans a state border. Portland, OR, sits immediately south of the Columbia River and Vancouver, WA, lies immediately to the north of the Columbia. While the two cities are subject to common federal laws (such as the US Clean Water Act), those laws are implemented by different state agencies within the context of differing regional and local governance structures. This contrast provides a relatively unique opportunity to investigate how differing governance systems collect and interpret information about the biophysical system and how differing governance systems impact the biophysical system over time.

Funded by US National Science Foundation, this study is a part of the Portland–Vancouver Urban Long-Term Research Area (PV ULTRA-Ex), a collaborative effort between natural scientists and social scientists. This interdisciplinary team of scientists and community partners are addressing the following research questions to understand the complex interactions and feedbacks among landscape patterns, water quality, green infrastructure and storm water management, riparian greenspace conservation and management, civic ecology, and environmental education in the CHANS system (see Fig. 1).

1. How do differences in local and state levels of *governance* and policy *affect* the *resilience* of both social and ecological landscapes?
2. How do alternative *land use planning* strategies affect *provision of ecosystem services* in response to different disturbance factors?
3. How effectively do the processes and outcomes of *monitoring* ecosystem services provide a *usable feedback loop* in urban socio-ecological systems?

2 Conceptual framework and research questions

Increasingly, the Coupled Human and Natural Systems (CHANS) (Liu et al., 2007) or Socio-Ecological Systems (SES) framework (Ostrom 2009) has been used in understanding the complex interactions between society and nature in urban areas. For example, Chowdhury et al. (2011) explained the evolution of urban residential landscape across four US cities using the CHANS framework, while Hager et al. (2013) sought to understand the differences in water quality improvements as they relate to urban revitalization in two contrasting neighborhoods in Baltimore using the SES lens. However, few authors have examined the complex multiple interactions and feedbacks among landscape pattern, water quality, environmental governance, and property sale prices.

Our study contributes to the expanding body of literature in urban ecosystem studies using the SES framework (Redman et al., 2004). It is one of the first attempts to investigate the degree of linkages among environmental governance, riparian conditions, land development pattern, and water quality in two adjacent urban areas. As such, it fills a gap in the literature by investigating a less explored area of urban ecosystems studies, namely the relationship between water quality and governance. Furthermore, with an explicit engagement of water quality managers and other governance stakeholders, the paper contributes to the nascent field of sociohydrology, an interdisciplinary field studying the dynamic interactions and feedbacks between water and people (Pataki et al., 2011; Sivapalan et al., 2012).

We focus on the following research questions under the overarching theme of "Does governance matter to water quality?"

1. Does monitoring effort differ as a function of governance?
2. Do riparian conditions differ between the two watersheds and do they correlate with indicators of water quality?
3. Do land development patterns differ between the two watersheds and do they correlate with water quality?
4. Is there a relationship between water quality and the sale price of properties and, if so, does that relationship vary between the two watersheds?

Questions (1) and (2) examine the potential for *direct and intentional* pathways between water quality and water governance. If such pathways are found, one might hypothesize a straightforward coupling of biophysical landscapes and environmental governance in which local governments collect scientific information about the ecosystem in order to take intentional, effective policy action.

Questions (3) and (4) examine *indirect and unintentional* pathways between water quality and environmental governance. If present, these pathways point toward a much more complex coupling in which the relationship between governance and water quality is primarily an unintended consequence of other interactions between natural and human systems. Both direct and indirect pathways might matter. The relative significance of direct or indirect pathways might differ under differing forms of governance.

In order to visualize the multiple and complex relationships between the biophysical and human/social domains in our system, we have developed a conceptual diagram (Fig. 2). The diagram exhibits a spectrum of possible linkages between water quality and governance. We are primarily interested in two types of pathways that might operate very differently: first, those that link water quality and governance directly and, in the case of human action, intentionally; second, those for which the connection between water quality and governance may be an unintended consequence of other connections between biophysical and social systems. Intentional or direct connectivity between water quality and environmental governance are represented by thick solid arrows in Fig. 2, while those that are less direct or less intentional are represented by dashed arrows. This is intended to capture the likelihood that not all pathways by which water quality characteristics eventually impact governance are direct and not all policy actions that eventually impact water quality are intended to do so.

In this paper, we only examine four possible linkages – (1) the impact of governance system on water quality monitoring; (2) the impact of changes in riparian conditions on water quality change; (3) the relationship between land cover change and water quality change; and (4) the relationship between water quality and property sales price. Each of these is an example of direct (1 and 2) or indirect (3 and 4) pathways by which water quality characteristics might reach institutions of government and government policy might impact water quality. Water quality monitoring generates scientific information that would seem to be of direct relevance to water quality management. Property sale prices are generated through economic rather than scientific behavior and represent an indirect pathway by which human perception and valuation (including perception and valuation of local water quality) reaches the attention of policy makers and government managers (Fischel, 2010). Riparian zone restoration and protection and land use policy are examples of policies that might be expected to impact water quality. While riparian restoration projects may be undertaken for a number of reasons (e.g., improved feeding habitat for fish and other consumers, erosion control, etc.), improvement of water quality is a common intention of such policies. Conversely, while land use policy has obvious implications for water quality, the preservation of farmland, and the avoidance of the costs of government services due to sprawl, are much more frequently cited as the primary goals of land use regulation (Abbott et al., 1994), as broadly defined as environmental policy.

3 Materials and methods

3.1 Study area

Our study area is located in the Portland–Vancouver Combined Metropolitan Statistical Area (PVCMSA). The PVCMSA exhibits a typical marine west coast climate, with cool, wet winters and mild, dry summers. The area receives approximately 1000 mm of rain annually and more than half of the rainwater becomes runoff (Chang, 2007). The PVCMSA, home to more than two million residents, is one of the fastest growing MSAs in the US, growing by more than 25 % between 1990 and 2010 (US Census 2010). Some of this population growth has occurred at the expense of converting agricultural or forested lands to urban residential lands (Fig. 3). According to the USGS national land cover classification, urban land cover increased from 58 % to 83 % in Portland and from 52 % to 86 % in Vancouver between 1992 and 2006. Previous studies on water quality in the PVCMSA report that the spatial and temporal variations of water quality are associated with land cover, building density and topographic variables (Pratt and Chang, 2012).

While the PVCMSA share similar biophysical characteristics, the two cities and surrounding counties have different land development histories and governance structures. Since the adoption of the urban growth boundary in 1973 as part of comprehensive land use planning, Portland has encouraged higher density in-fill development, minimizing the sprawled development that is found in many US cities. In contrast, communities in Washington were not required to address urban growth management until the statewide Growth Management Act was passed in 1990 and implemented (in Clark County, Washington) in 1994, resulting in a greater loss of agricultural and forest land than in Portland.

Because the PVCMSA covers a wide geographical area, we chose two representative creeks – Burnt Bridge Creek, located in the city of Vancouver, WA, and Johnson Creek, located primarily within the city of Portland, OR – for our case study (Fig. 3). These two creeks were chosen because (1) they have undergone significant land cover change in the past two decades; (2) water quality has been a concern with both creeks listed as impaired streams under article 303(d) of the Clean Water Act; and (3) both creeks have been the target of state and local policy intervention.

3.2 Data and methods

Water quality data were obtained from multiple agencies: US Geological Survey, Oregon Department of Environmental Quality, the City of Portland – Bureau of Environmental Services, Washington Department of Ecology, and Clark County, WA. We selected stream temperature as a barometer of stream health since it not only reflects the physical water quality condition, but also affects the rate of in-stream biochemical cycling and thus has an impact on fish habitat (Caissie, 2006). Additionally, stream temperature data have been collected more frequently than other water quality parameters in the study areas. We only used governmental agency data, so any water quality data collected by citizens and NGOs were excluded from our analysis. Land cover data were acquired from the USGS national land cover data set (USGS, 2012) at the 30 m spatial resolution for two years – 1992 and 2006 – representing snapshots of land cover change. We used ArcGIS to derive the distribution of land covers for each year by watershed. We used two sample means *t* test to identify if mean stream temperatures differed between the two periods (1990s vs. 2000s).

Changes in riparian areas between 1990 and 2008 were estimated based on aerial photo analysis following the methods described elsewhere (Ozawa and Yeakley, 2007; Yeakley et al., 2012). Aerial photos were analyzed at 0.3 m resolution for all permanent streams within the 1990 city boundaries of Portland and Vancouver. Vegetation cover was classified as either “woody” (i.e. trees and shrubs) or “unmanaged” (e.g. greenspaces, unmanaged vacant lots), and as either in a contiguous patch connected to the stream (i.e., “adjacent”) or just existing within a specific buffer width from the stream. Buffer widths analyzed included distances from the top of stream bank spanning from 7.5 m to 100 m. The close-in buffer widths represent areas that are most amenable to policy and management practices intended to conserve riparian buffers, while buffer widths at 100 m are more representative of general development pressure.

Single-family residential property sale data for 2005–2007 were obtained from the Multnomah County, OR, and Clark County, WA, Assessors. We used the hedonic price method, a statistical technique, to examine if water quality is correlated with the sale price of single-family properties sold between 2005–2007 within a 2-mile buffer of Johnson Creek and Burnt Bridge Creek. We associated 10 479 property transactions from 2005–2007 within a 2-mile buffer of Johnson Creek with water quality at the nearest water quality monitoring site in the year the property was sold. We associated 5093 property transactions that occurred within a 2-mile buffer of Burnt Bridge Creek between 2005–2007 with water quality at the nearest water quality monitoring station in 2007.

Data on governance and policy were collected through 19 semi-structured interviews with public officials and other stakeholders across a range of levels of government and areas of responsibility. Interviews were transcribed and analyzed using Dedoose software. The data were supplemented through a review of state and local government documents and media reports.

4 Results and discussion

4.1 Relationship between water governance and water quality monitoring

Water quality monitoring has a long history in both Burnt Bridge Creek (Vancouver) and Johnson Creek (Portland), though the characteristics of that monitoring have changed over time. Most significantly for the present study, the intensity and purpose of monitoring differs considerably between the two cities despite the uniformity in federal law (i.e. the Clean Water Act) and Pacific Northwest political culture. This contrast appears to be due to differences in state and local governance and in the timing and nature of development on the two sides of the Columbia River.

In the 1970s and 1980s, water quality was monitored more frequently in Burnt Bridge Creek than in Johnson Creek (Fig. 4). This difference reflects the specific concerns of local managers in an area rapidly transitioning from rural to urban development. In the 1970s, Clark County officials working to develop a restoration plan for Vancouver Lake (a floodplain lake within the city of Vancouver, and the terminal catchment for Burnt Bridge Creek) identified septic tank systems in the Burnt Bridge Creek watershed as a major source of contamination (Starr, 1996). Between 1978 and 1995, a Vancouver city program identified nearly 1000 aging septic systems and helped connect them to the city sewer system (Callahan, 1995). The consistent water quality monitoring regime during this period appears to have been motivated by local concerns for human health and recreation.

In the 1990s, both streams were listed as “impaired waters” under Sect. 303(d) of the federal Clean Water Act (CWA). Johnson Creek was added to the list by the Oregon Department of Environmental Quality (ODEQ) in 1998 and its total maximum daily loads (TMDLs) were approved by the US Environmental Protection Agency in 2006. The Washington Department of Ecology (WADE) added Burnt Bridge Creek to the CWA 303(d) list in 1996, but the TMDLs are still under development.

The much longer time frame between 303(d) listing and TMDL approval in Burnt Bridge Creek is indicative of a more litigious and contentious governance process in

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Vancouver, a process which has affected the quantity and purpose of stream monitoring. For some time WADE had been pressuring Vancouver and Clark County officials to work to restore the creek to a condition fit for swimming and fishing (Callahan, 1995). Stakeholders reported in interviews, however, that local officials argued that Burnt Bridge Creek was now an urban stream and that restoration to pre-urban conditions was impractical. Water quality monitoring in Burnt Bridge Creek actually declined in the years following the 303(d) listing, the opposite of the response in Portland's Johnson Creek (Fig. 4) when Portland's Bureau of Environmental Services started regular stream monitoring in the late 1990s.

Public participation in the political and legal process also drives water quality monitoring in Vancouver. Monitoring efforts increased dramatically in the second half of the 2000s. This appears to have been partly in response to citizen complaints and a CWA lawsuit filed in 2004 by a neighborhood association and a local environmental organization. The plaintiffs and the City of Vancouver settled the lawsuit in a signed agreement approved by the city council in May of 2006 (Mize, 2006). In the document, Vancouver agreed, among other things, to "develop and implement a long term water quality monitoring program to generate data regarding water quality in Burnt Bridge Creek" (Settlement 2006). A further increase in monitoring in 2008 and 2009 reflects WADE's intensified efforts to develop the TMDLs for Burnt Bridge Creek (Water Quality Improvement Project, 2011).

Today, water quality monitoring in Vancouver is still primarily driven by issues of legal compliance and is constrained by budgetary limitations. Even advocates of monitoring for other purposes recognize the importance of these external regulatory drivers. As a Vancouver city government technician put it, "The budget constraints mean that we are doing essentials only . . . The state and federal mandates may be hammers but they also justify the funds."

The CWA has been an important driver of water quality governance in Portland as well, particularly with regard to violations stemming from storm water runoff and combined sewer overflows. In 1991, with amendment in 1994, the ODEQ reached an agreement with the City of Portland Bureau of Environmental Services to allow innovative and experimental initiatives such as downspout disconnect programs and the construction of green street infrastructure to be part of management efforts in addition to conventional pipe replacement and the construction of an ambitious 6 mile long connecting tunnel (East Side Big Pipe, 2011). In 2011, ODEQ commended Portland for meeting all milestones and requirements of the agreement (Pendersen, 2011).

This emphasis on local innovation and experimentation in Portland, with state level approval, has had an impact on water quality monitoring. Interviewees report robust budgets for monitoring. Interviews and public documents show an emphasis on the value of monitoring as applied science to inform adaptive management. In 2010 the city established the Portland Area Watershed Monitoring and Assessment Program (PAWMAP) using protocols developed by the EPA's Environmental Monitoring and Assessment Program. The goal of the PAWMAP is to go beyond compliance "to consistently track and communicate progress under the PWMP (Portland Watershed Management Plan), guide discussions about targets for improvement in local watersheds, and illustrate what investments or activities make the most difference for rivers and streams" (Portland Watershed Management Plan 2011). One indication of Portland's commitment to monitoring beyond the requirements of compliance may be seen in the continued high level of monitoring after the EPA's approval of Johnson Creek TMDLs in 2006.

To summarize our findings for question one, we found that governance has a significant impact on water quality monitoring. Monitoring in both streams is heavily influenced by regulatory mandates. But differences in governance were reflected in differences in the quantity and purpose of monitoring. In Vancouver, monitoring is largely done for the purpose of compliance with state and federal legal requirements and in response to citizen complaints. Legal action, state intervention and budgetary constraints have led to fluctuations in the quantity of monitoring. In Portland, while compliance with legal mandates is a driver as well, water quality monitoring is increasingly viewed as

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a tool for understanding what does and does not work to improve water quality and ecosystem health.

4.2 Watershed land development, riparian vegetation and stream temperature

Both Vancouver, WA and Portland, OR (and the entire PVCMSA) have been subject to rapid population growth and development pressure since the 1970s. Land use management has been an explicit goal of urban governance for more than three decades. Land use policy for most of this time, however, was not done to explicitly protect water quality. Rather, it was aimed at the containment of urban growth to preserve forest and farm land. Both cities established urban growth boundaries for this purpose, though differences in state law and local politics caused the Vancouver boundary to be implemented later and expanded more frequently than was the boundary in Portland (Kline et al., 2013; Thiers et al., 2013).

It is well known that increasing urban land cover, which increases impervious surface areas, is associated with changing hydrology and water quality (Paul and Meyer, 2001; Chang, 2007). However, no consensus exists regarding which spatial scale is more influential in determining water quality conditions. While some studies have identified watershed-wide land cover as a more important factor affecting water temperature than riparian land covers (e.g., Scott et al., 2002), others report the opposite cases (e.g., Cunningham et al., 2010; Yu et al., 2013). Since more than half of both the Johnson Creek and Burnt Bridge Creek watersheds are already urbanized and further land development pressures still exist (Fig. 5), identifying target areas for environmental conservation has been a prime concern in both Portland and Vancouver. Since riparian canopy cover is one of the most significant physical variables controlling a stream's heat budget (Caissie, 2006; Chang and Psaris, 2013), restoring riparian vegetation has been used as an important strategy in stream restoration (Roth, 2002), particularly in Burnt Bridge Creek where less land is available for conservation.

Changes in riparian areas include both losses in woody and unmanaged vegetated areas due to development pressure and gains due to both restoration activities and natural growth of existing vegetation. Riparian areas showed consistent losses during the earlier period (1990–2002) for both cities, with greater losses in unmanaged vegetation for Vancouver and in woody vegetation for Portland (Fig. 5). In the more recent period (2002–2007/2008), there were significant increases in riparian gains for both woody and unmanaged vegetation classes for both cities (Fig. 5). In both cities, gains in riparian area outpaced losses in the latter period for the 7.5 m and 15 m buffer widths. A general observation is that, while Portland and Vancouver have varying riparian management policies, both cities showed success in conserving and restoring these greenspaces that are critical to the maintenance of water quality.

At the whole watershed scale, urban land cover is the dominant land cover and has increased by 31 % and 21 % in BBC (Burnt Bridge Creek) and JC (Johnson Creek), respectively, between 1992 and 2006 (Fig. 6). This urban expansion occurred at the expense of both agricultural and forest land cover. In particular, agricultural and forest lands shrank to 3 % and 1 % respectively of the Burnt Bridge Creek watershed between 1992 and 2006. In the Johnson Creek watershed agricultural and forest lands have each remained approximately 15 % of the total land cover in 2006. The enormous urban growth in Burnt Bridge Creek is attributed to the fact that almost all areas of the watershed reside within the city limits of Vancouver as the urban growth boundary expanded during the study period. By contrast, a significant portion of the Johnson Creek watershed remains outside of the urban growth boundary, and is composed of farmlands or forests or rural residential areas. Albeit small, wetlands areas have increased from 0.1 % to slightly less than 1 % in both watersheds.

When changes in land cover at the whole watershed scale and the buffer scale are associated with changes in water temperature, there is no clear relationship between the two. As shown in Fig. 7, there are no substantial changes in dry season (May to October) water temperature from the 1990s to the 2000s in either watershed. While Johnson Creek had a similar range of water temperature in both the 1990s and the

2000s, Burnt Bridge Creek had a slightly higher water temperature range in the 2000s than in the 1990s. This is likely due to a more intense sampling in the late 2000s following the lawsuit discussed above.

Considering that urban areas have expanded more than 20 % in both watersheds during the study period, it is notable that water quality did not degrade significantly. In this regard, both cities have protected water quality to some extent. While Vancouver appears to have accomplished this directly by protecting and restoring riparian areas, Portland may have achieved this primarily through land use planning by keeping headwater source regions outside of the urban growth boundary. Even though the policy mechanism employed differs across the two watersheds, the outcomes of environmental management, in this case maintaining healthy stream conditions, do not differ in a statistically significant way.

4.3 Perception: relationship between property sale prices and water quality

Numerous studies have found a relationship between the sale price of single-family residential properties and water quality (Leggett and Bockstael, 2000; Gibbs et al., 2002; Poor et al., 2007). Water quality parameters that were most likely to be perceived by residents were selected for analysis. For example, total suspended solids (TSS) affects water clarity; dissolved oxygen (DO), temperature and pH may impact fish and wildlife populations; and *E. coli* or fecal coliform concentration may produce foul odors. *A priori* we expected that increases in *E. coli* (in Johnson Creek) or fecal coliform concentration (in Burnt Bridge Creek), TSS, pH, and water temperature would have a negative effect on sale price, while increases in DO would have a positive effect. We believe that perceptions of water quality, rather than knowledge about the water quality measurements themselves, affects the sale price of single-family residential properties near Johnson Creek and Burnt Bridge Creek, and that estimated impacts would vary based on a property's distance from each creek.

Figure 8a presents a summary of our findings for Burnt Bridge Creek and Fig. 8b for Johnson Creek. The results for *E. coli* in Johnson Creek are statistically and economically significant, with estimated effects from a 100 *E. coli* per mL increase ranging from −2.41 % for properties within 1/4 mile of Johnson Creek to −0.65 % for properties located more than 1 mile from the creek. Findings for TSS were stronger in Burnt Bridge Creek than Johnson Creek with a 1 $\mathrm{mg\,L^{-1}}$ increase estimated to have a statistically negative effect of −0.66 % and −0.82 % for properties within 1/4 mile and 1/2 mile of the creek, respectively. pH has a large and significantly negative estimated impact on property values in Burnt Bridge Creek. Algae blooms in Vancouver Lake, which are correlated with pH levels (amongst other environmental variables), may explain this result (Lee et al., 2013). Temperature has a significantly negative effect for properties located within 1/4 mile of Johnson Creek, but it is significant only for properties located more than a mile from Burnt Bridge Creek. DO results are negative and statistically significant in both study areas, but the estimated effects are much larger in Johnson Creek. This may be a result of the presence of listed species such as Steelhead and Coho Salmon in Johnson Creek and a demonstrated willingness of residents in the Johnson Creek area to pay for programs that improve fish and wildlife habitat (Larson and Lach, 2008).

5 Conclusions

Using a CHANS framework in sociohydrology, we investigated the potential interactions and feedbacks between governance and water quality. Our analyses show the following results. First, water governance has affected stream monitoring regimes in both watersheds, but the effects of different monitoring efforts on stream health, as indicated by water temperature, is not different across the watersheds within the timeframe of this study. Second, both watersheds experienced rapid urban growth in the past two decades; however, through varying institutional policies, riparian vegetation cover has increased in both cities and the headwaters of Johnson Creek were protected through exclusion from the urban growth boundary. As a result, both cities were able to maintain ambient water quality regardless of ongoing urban development. Third, there is a strong feedback in human perception on water quality as indicated by the strong relationship between water quality and the sale price of single-family residential properties.

Further studies are needed to uncover the dynamics of changing environmental governance and water quality at multiple levels. A survey of residents' perceptions about water quality and governance has been collected and is being analyzed by other researchers in the PV ULTRA-Ex project. Analysis of this survey may provide additional insight into how human perceptions and environmental governance regimes differ across the two watersheds. Additionally, since most urban streams typically exhibit legacy effects that have been inherited from some decades ago, it is important to trace land development policy and its impacts on land surface hydrology from historical geographic perspectives. Related to this is a need to continue stream monitoring to be able to detect any future changes in water quality as they relate to changes in land development patterns and policy. It may be that differences in governance will have more significant impacts on water quality over longer time periods. Finally, since there are multiple pathways to improve ambient water quality, it is necessary to assess potential tradeoffs among different management strategies such as point source control by big pipes or waste water treatment plant, semi-distributed riparian vegetation cover creation, and installation of green infrastructure. Assessing these tradeoffs may help to inform policy makers as they consider the economic and political transaction costs associated with different ways to manage water quality.

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References

Abbot, C., Howe, D. A., and Adler, S.: Planning the Oregon way: a twenty year evaluation, Oregon State Univ. Press, Corvalis, OR, 1994.

Bunch, M. J., Morrison, K. E., Parkes, M. W., and Venema, H. D.: Promoting health and well-being by managing for social-ecological resilience: the potential of integrating ecohealth and water resources management approaches, Ecol. Soc., 16, http://www.ecologyandsociety.org/vol16/iss1/art6/, 2011.

Caissie, D. The thermal regime of rivers: a review, Freshwater Biol., 51, 1389–406, 2006.

Callahan, L.: Bad water in Burnt Bridge, The Columbian, Vancouver, WA, A3, 4 Dec. 1995.

Carey, R. O., Migliaccio, K. W., Li, Y. C., Schaffer, B., Kiker, G. A., and Brown, M. T.: Land use disturbance indicators and water quality variability in the Biscayne Bay watershed, Florida, Ecol. Indic., 11, 1093–1104, 2011.

Chang, H.: Streamflow characteristics in urbanizing basins in the Portland Metropolitan Area, OR, USA, Hydrol. Process., 21, 211–222, 2007.

Chang, H. and Psaris, M.: Local landscape predictors of maximum stream temperature and thermal sensitivity in the Columbia River basin, USA, Sci. Total Environ, doi:10.1016/j.scitotenv.2013.05.033, in press, 2013.

Cho, S. H., Roberts, R. K., and Kim, S. G.: Negative externalities on property values resulting from water impairment: the case of the Pigeon River watershed, Ecol. Econ., 70, 2390–2399, 2012.

Chowdhury, R., Larson, K., Grove, J. M., Polsky, C., Cook, E., Onsted, J., and Ogden, L.: A multi-scalar approach to theorizing socio-ecological dynamics of urban residential landscapes, Cities Environ., 4, http://digitalcommons.lmu.edu/cate/vol4/iss1/6/, 2011.

City of Portland, Bureau of Environ. Services: Portland watershed management plan, available at: www.portlandoregon.gov/bes/article/338860, last access: 15 November 2011.

City of Vancouver, Rosemere Neighborhood Assoc. and Clark Co. Nat. Res. Council: Settlement reached in local Clean Water Act case, Approved joint public statement, 2006.

Cunningham, M. A., Menking, K. M., Gillikin, D. P., Smith, K. C., Freimuth, C. P., Belli, S. L., Pregnall, A. M., Schlessman, M. A., and Batur, P.: Influence of open space on water quality in an urban stream, Phys. Geogr., 31, 336–356, 2010.

Dearing, J. A., Bullock, S., Costanza, R., Dawson, T. P., Edwards, M. E., Poppy, G. M., and Smith, G. M.: Navigating the perfect storm: research strategies for socialecological systems in a rapidly evolving world, Environ. Manage., 49, 767–775, 2012.

East Side Big Pipe, Portland Bureau of Environmental Services, available at: http://www.portlandoregon.gov/bes/article/201984, last access: 15 November 2011.

Fischel, W. A.: The Homevoter hypothesis: how home values influence local government taxation, school finance, and land-use policies, Harvard University Press, 2009.

Gibbs, J. P., Halstead, J. M., Huang, J. C., and Boyle, K. J.: An hedonic analysis of the effects of lake water clarity on New Hampshire lakefront properties, Agr. Resource Econ. Rev., 31, 39–46, 2002.

Golden, H. E. and Knights, C. D.: Simulated watershed mercury and nitrate flux responses to multiple land cover conversion scenarios, Environ. Toxicol. Chem., 30, 773–786, 2011.

Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., and Yalcin, R.: Adaptive water governance: assessing the institutional prescriptions of adaptive (co-) management from a governance perspective and defining a research agenda, Ecol. Soc., 14, 1–19, 2009.

Jan, S. R.: A revised framework for coupled human and natural systems, propagating thresholds, and managing environmental problems, Phys. Chem. Earth, 36, 342–351, 2011.

Kline, J. D., Thiers, P., Ozawa, C. P., Yeakley, J. A., and Gordon, S. N.: Examining land use planning outcomes in the Portland, OR-Vancouver, WA (USA) metropolitan area under contrasting planning regimes, in review, 2013.

Larson, K. L. and Lach, D.: Participants and non-participants of place-based groups: an assessment of attitudes and implications for public participation in water resource management, J. Environ. Manage., 88, 817–830, 2008.

Lee, T. A., Rollwagen Bollens, G. C., and Bollens, S. M.: The influence of water quality variables on cyanobacteria blooms and phytoplankton community composition in a shallow temperate lake, Lake Reserv. Manage., in review, 2013.

Leggett, C. G. and Bockstael, N. E.: Evidence of the effects of water quality on residential land prices, J. Environ. Econ. Manage., 39, 121–144, 2000.

Liu, J., Dietz, T., Carpenter, S., Alberti, M., Folke, C., Moran, E., Pell, A., Deadman, P., Kratz, T., Lubcheno, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C., Schneider, S., and Taylor, W.: Complexity and coupled human and natural systems, Science, 317, 1513–1516, 2007.

McConnell, W. J., Millington, J. D. A., Reo, N. J., Alberti, M., Asbjornsen, H., Baker, L. A., Brozovic, N., Drinkwater, L. E., Drzyzga, S. A., Fragoso, J., Holland, D. S., Jantz, C. A., Kohler, T. A., Maschner, H. D. G., Monticino, M., Podesta, G., Pontius, R. G., and Redman, C. L.: Research on coupled human and natural systems (CHANS): approach, challenges, and strategies, Bull. Ecol. Soc. Am., 92, 218–228, 2011.

Mize, J.: Suit over storm water settled, The Columbian, C3, 12 May 2006.

Netusil, N. R., Kincaid, M., and Chang, H.: Valuing water quality in urban watersheds: a comparative analysis of Johnson Creek, Oregon and Burnt Bridge Creek, Washington, in review, 2013.

Ostrom, E.: A general framework for analyzing sustainability of social-ecological systems, Science, 325, 419–422, 2009.

Ozawa, C. P. and Yeakley, J. A.: Performance of management strategies in the protection of riparian vegetation in three Oregon cities, J. Environ. Plann. Man., 50, 803–822, 2007.

Pataki, D., Boone, C. G., Hogue, T. S., Jenerette, G. D., McFadden, J. P., and Pincetl, S.: Socio-ecohydrology and the urban water challenge, Ecohydrology, 4, 341–347, 2011.

Paul, M. J. and Meyer, J. L.: Streams in the urban landscape, Annu. Rev. Ecol. Syst., 32, 333–365, 2001.

Pendersen, D.: Oregon Department of Environmental Quality Memorandum to the Environmental Quality Commission, 28 January 2011.

Pickett, S. T. A., Buckley, G. L., Kaushal, S. S., and Williams, Y.: Social-ecological science in the humane metropolis, Urban Ecosyst., 14, 319–339, 2011.

Pratt, B. and Chang, H.: Effects of land cover, topography, and built structure on seasonal water quality at multiple spatial scales, J. Haz. Mat., 209/210, 48–58, 2012.

Poor, P. J., Pessagno, K. L., and Paul, R. W.: Exploring the hedonic value of ambient water quality: a local watershed-based study, Ecol. Econ., 60, 797–806, 2007.

Redman, C. L., Grove, J. M., and Kuby, L. H.: Integrating social science into the long-term ecological research (LTER) network: social dimensions of ecological change and ecological dimensions of social change, Ecosystems, 7, 161–171, 2004.

Roth, T. R., Westhoff, M. C., Huwald, H., Huff, J. A., Rubin, J. F., Barrenetxea, G., Vetterli, M., Parriaux, A., Selkeer, J. S., and Parlange, M. B.: Stream temperature response to three riparian vegetation scenarios by use of a distributed temperature validated model, Environ. Sci. Technol., 44, 2072–2078, 2010.

Scott, M. C., Helfman, G. S., McTammany, M. E., Benfield, E. F., and Bolstad, P. V.: Multiscale influences on physical and chemical stream conditions across Blue Ridge landscapes, J. Am. Water Resour. As., 38, 1379–1392, 2002.

Sharpley, A. N., Kleinman, P. J. A., Flaten, D. N., and Buda, A. R.: Critical source area management of agricultural phosphorus: experiences, challenges, and opportunities, Water Sci. Technol., 64, 945–952, 2011.

Starr, L.: This week in Clark County history, The Columbian, Vancouver, WA, 9, 24 Oct. 1996.

Thiers, P., Stephan, M., and Walker, A.: Differences in regime and structure within an ecological region: comparing environmental governance in the Portland-Vancouver metropolitan area, Manuscript, in review, 2013.

US Geological Survey, Multi-Resolution Land Characteristics Consortium, available at: http://www.mrlc.gov/, last access: 15 May 2012.

Washington Department of Ecology: Water Quality Improvement Project: Burnt Bridge Creek Area, available at: http://www.ecy.wa.gov/programs/wq/tmdl/burntbridge/BurntBrTMDLpfv.pdf, last access: 21 October 2011.

Yeakley, J. A., Ozawa, C. P., Fisher de Leon, A. D., and Armstrong, C. M.: Gains and losses of urban riparian greenspaces in Portland–Vancouver, AWRA 2012 Summer Specialty Conference, Riparian Ecosystems IV: Advancing Science, Economics and Policy, Denver, CO, 1–5, 2012.

Yu, D. Y., Shi, P. J., Liu, Y. P., and Xun, B.: Detecting land use-water quality relationships from the viewpoint of ecological restoration in an urban area, Ecol. Eng., 53, 205–216, 2013.

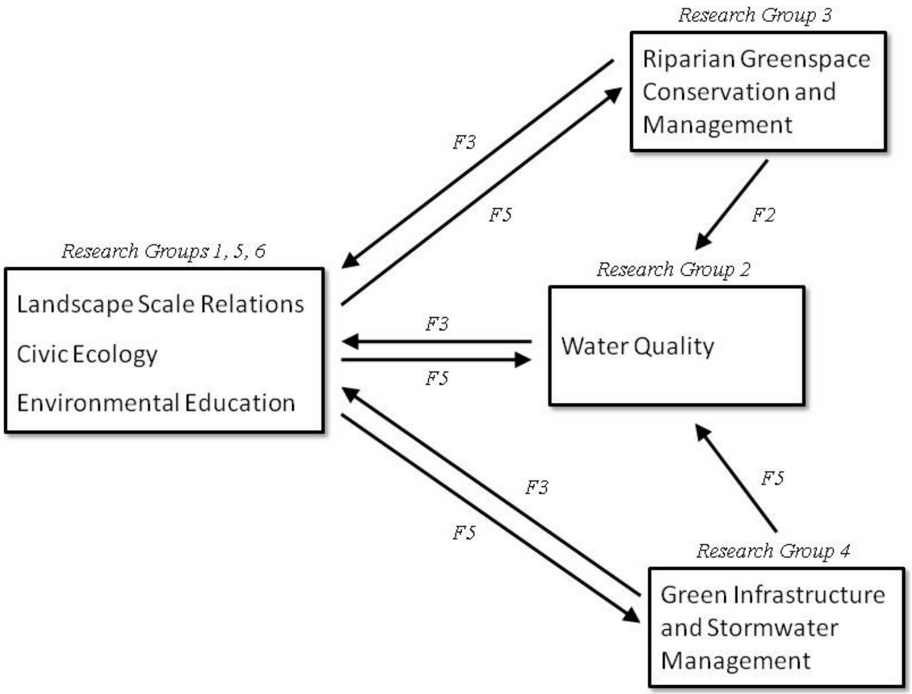

Fig. 1. Conceptual overview diagram of Portland Vancouver-ULTRA-ex (available at http://ultra.forestry.oregonstate.edu/research-group-linkages).

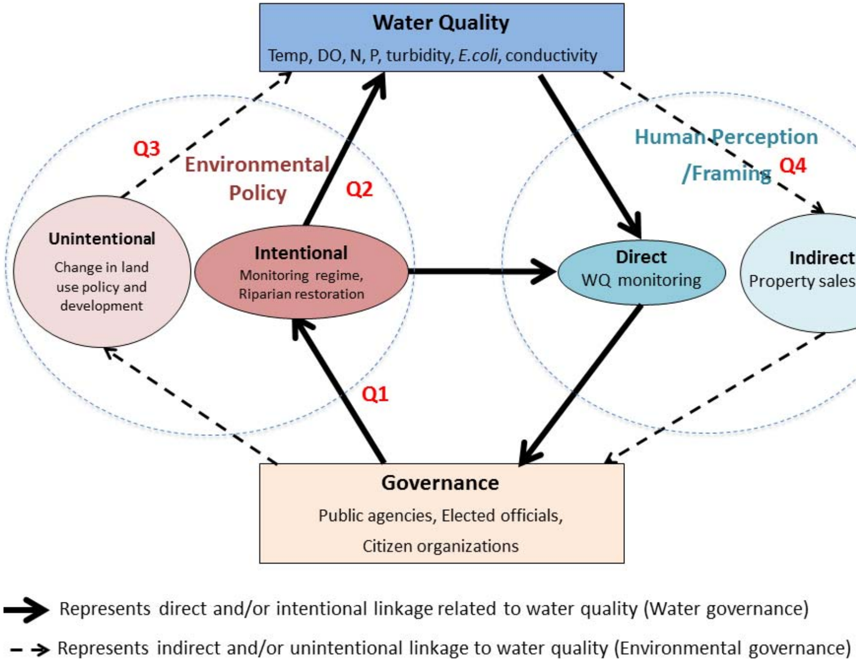

Fig. 2. Coupled natural and human systems framework for understanding the coupled environmental governance and water quality. Q1–4 are defined as follows:

- Q1 – Does monitoring effort differ as a function of governance?
- Q2 – Do riparian conditions differ between the two watersheds and do they correlate with indicators of water quality?
- Q3 – Do land development patterns differ between the two watersheds and do they correlate with water quality?
- Q4 – Is there a relationship between water quality and the sale price of properties and, if so, does that relationship vary between the two watersheds?

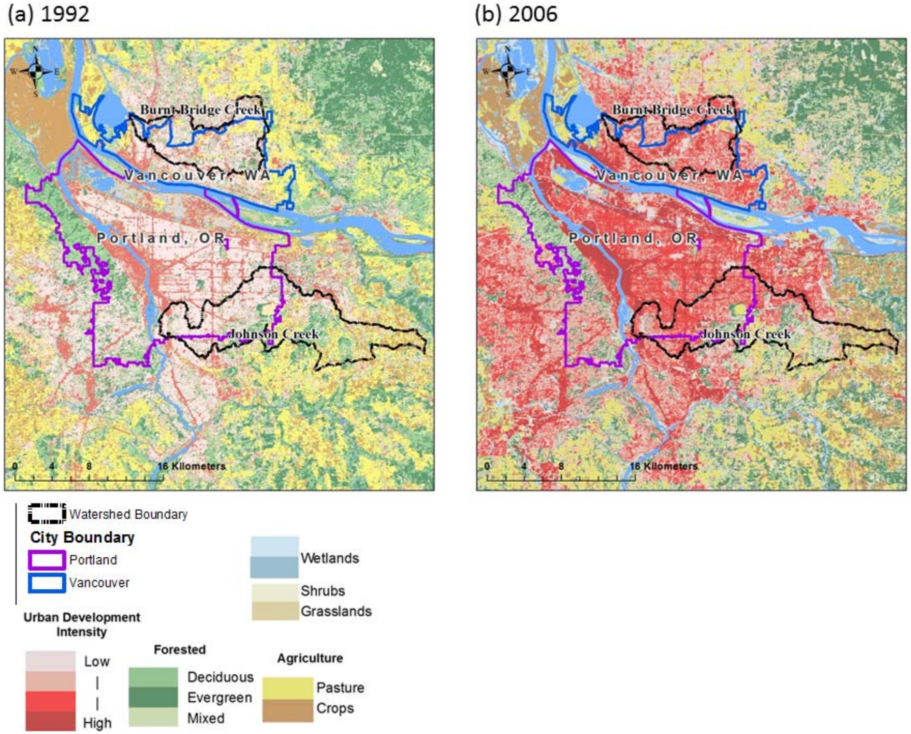

Fig. 3. Study watersheds boundary, city boundary and land cover classes in the study area, 1992–2006.

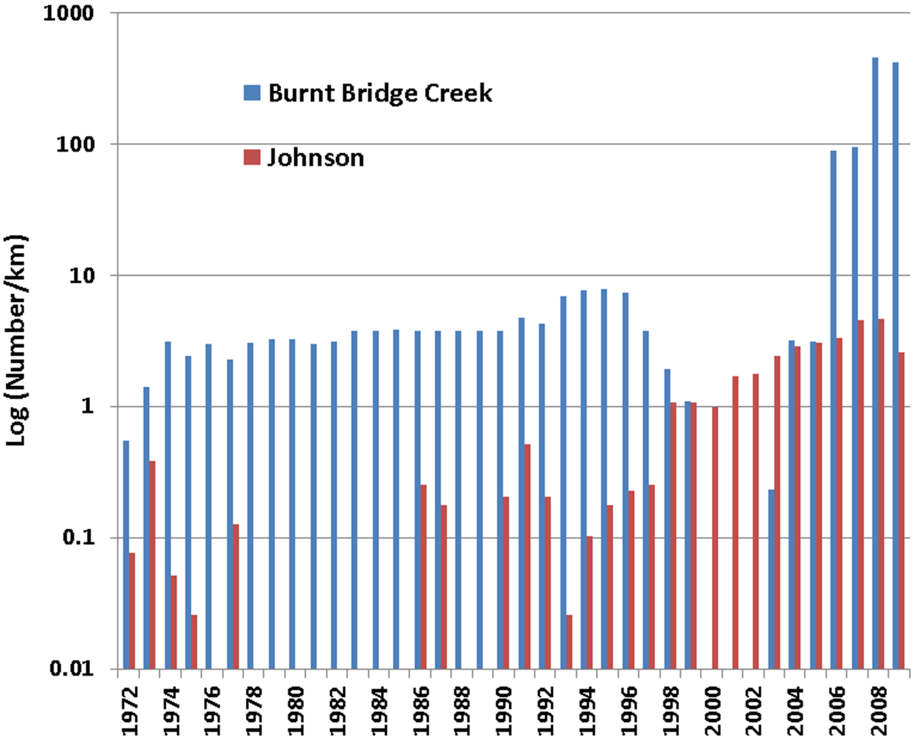

Fig. 4. Annual frequency of stream temperature monitoring normalized by stream length (km) in Burnt Bridge Creek and Johnson Creek. Number per stream length is log transformed.

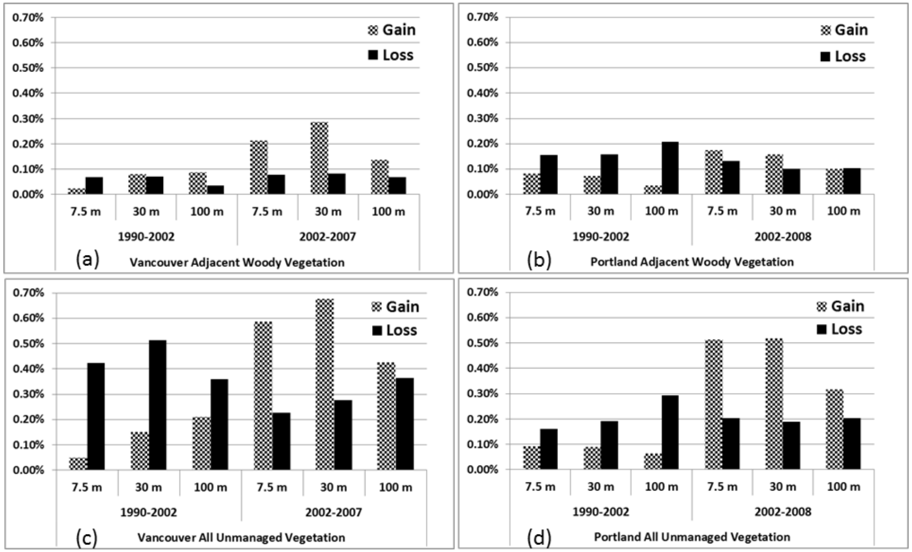

Fig. 5. Riparian Area Changes for Portland and Vancouver during 1990–2008. Shown are three buffer widths (7.5 m, 30 m, 100 m) for each two categories of riparian vegetation: **(a, b)** adjacent woody vegetation, i.e. contiguous patches of tree and shrub vegetation connected to stream; **(c, d)** all unmanaged vegetation, i.e. all vegetated riparian areas within the buffer, whether connected to stream or not. Methods of analysis follow Ozawa and Yeakley (2007).

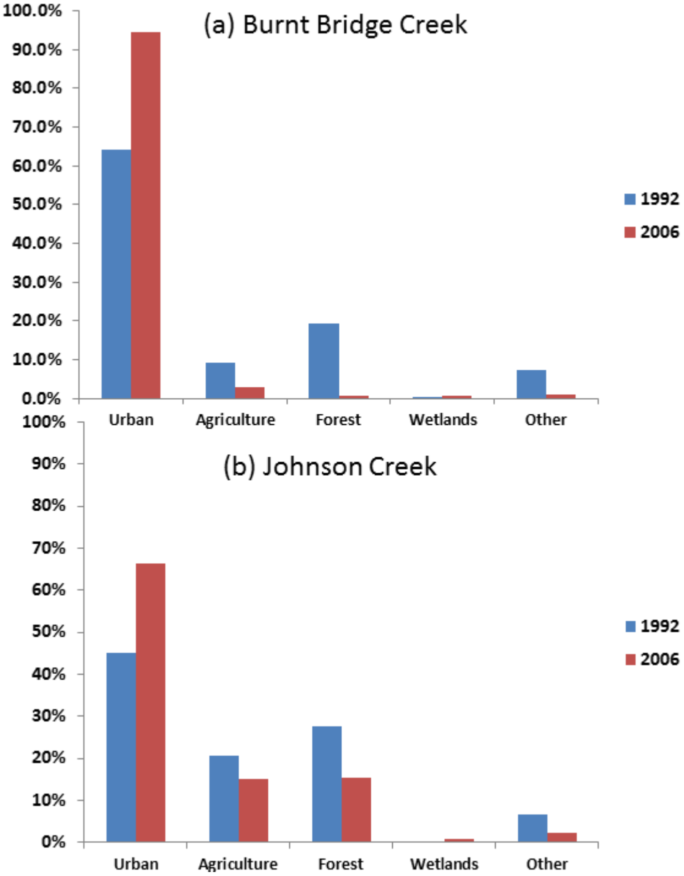

Fig. 6. Change in land cover distribution from 1992 to 2006 in **(a)** Burnt Bridge Creek and **(b)** Johnson Creek.

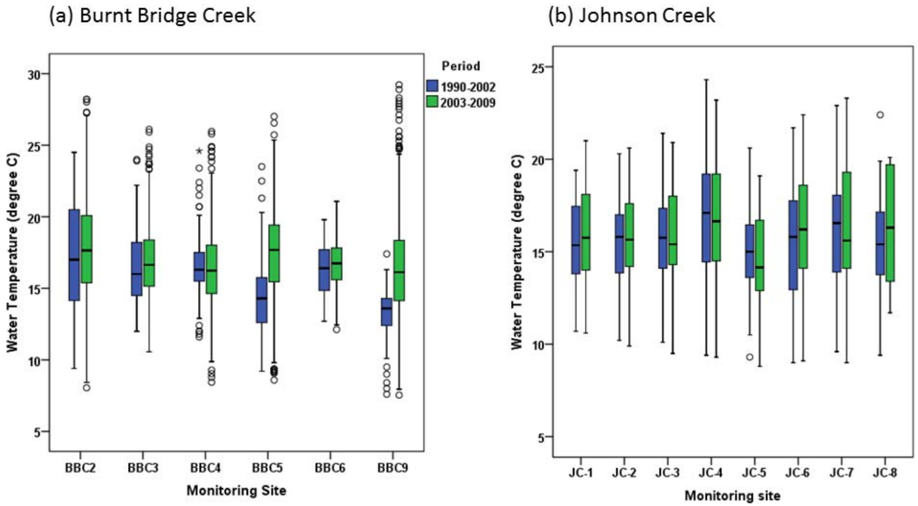

Fig. 7. Dry season (May to October) water temperature for each monitoring site during the 1990s and 2000s in **(a)** Burnt Bridge Creek and **(b)** Johnson Creek: sample size varies.

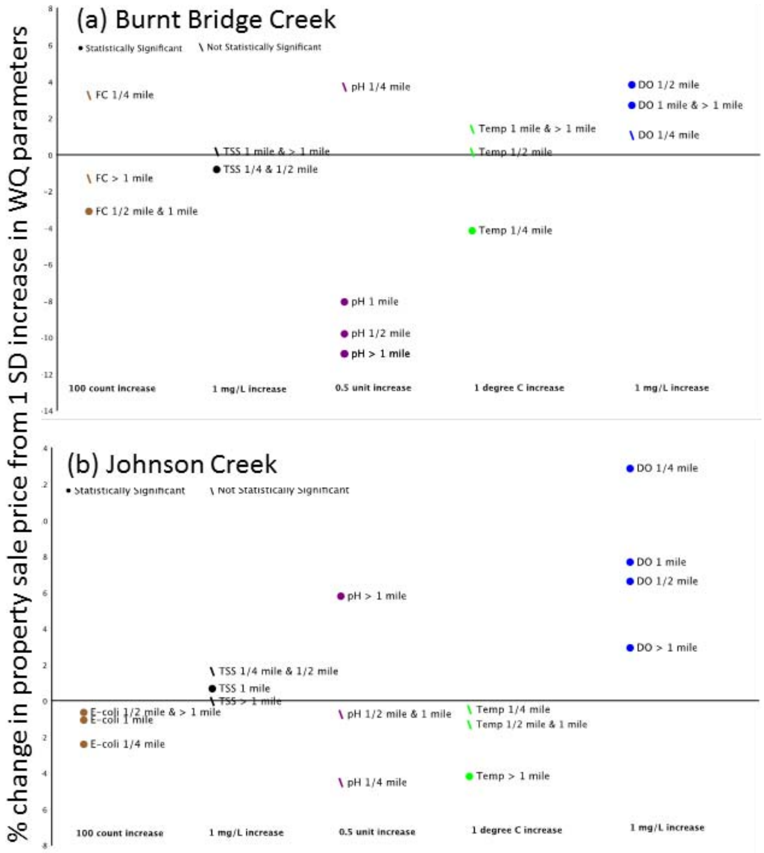

Fig. 8. Changes in property sales price with changes in water quality at multiple distances for **(a)** Burnt Bridge Creek watershed and **(b)** Johnson Creek watershed.

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