Proposal For OGW Groundwater Resources Program, FY 2010 challenge areas

Addressing Challenge Area 3: Monitoring effects of climate change on groundwater resources

Title: Quantifying effects of climate change on the snowmelt-dominated groundwater resources of northern New England

Principal Contacts:
Robert W. Dudley, Hydrologist, USGS Maine Water Science Center, 196 Whitten Road, Augusta, ME 04330; rwdudley@usgs.gov; (T) 207-622-8201 ext. 102; (F) 207-622-8204
James B. Shanley, Research Hydrologist, USGS New Hampshire/Vermont Water Science Center, P.O. Box 628, Montpelier, VT 05602; jshanley@usgs.gov; (T) 802-828-4466; (F) 802-828-4465

Background: Northern New England (Maine, New Hampshire, Vermont) is an ideal region to monitor the effects of climate change on groundwater (GW) resources because its water resources are dominated by snowmelt hydrology and the region is largely undeveloped with limited impacts from water use. Analyses of historical snowpack and streamflow data in northern New England have demonstrated that snowpack, snowmelt runoff, and summer baseflows have changed substantially during the last 100 years (fig. 1) (Hodgkins and Dudley, 2006a; 2006b; 2009). Two ongoing studies funded by the USGS Global Climate Change Program and the National Climate Change and Wildlife Science Center involve climate-change scenarios that are input to deterministic watershed models for several watersheds in Maine. Preliminary results project additional seasonal snowpack depletion, and even earlier snowmelt runoff in the next century. Because New England's fractured-bedrock aquifers have very little storage capacity, simulation of such changes in southeast New Hampshire (Mack, 2009) results in a decline in GW resources during summer months.

Problem: The lack of long-term (> 50 year) continuous GW records in northern New England hinders direct systematic examination of historical trends in GW resources as has been done for surface-water records, however GW data correlations with surface-water records and climatic data provide a means for historical assessment. Extensive analyses of surface-water records in New England have shown the importance of long-term data and have demonstrated problems with using data sets of only 30-50 years in length. For example, the 1960's were particularly cold and snowy and nearly any temporal analysis of winter/spring meteorological or hydrologic time series beginning in that time period will show changes consistent with warming. However, recent analyses of spring lake ice-out data for New England since the 1980's show few changes consistent with warming (Hodgkins, 2009). It is important to place trends from shorter periods of time into a longer-term perspective. It is also important to place hydroclimatic changes into a geographic context. For example, lake ice-out dates and trend results (Hodgkins, 2009) are different for different hydrologic climate-response regions (Hodgkins and others, 2009) in Maine.

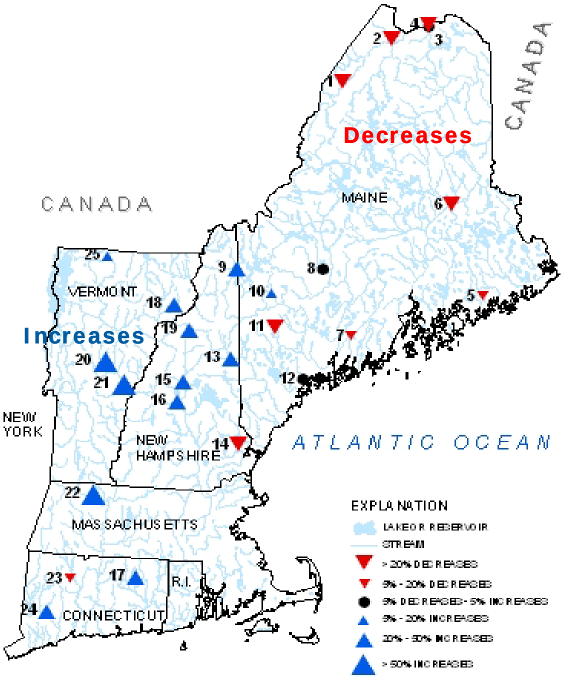

Figure 1 Summer baseflow trends in New England 1950-2006.

Proposal For OGW Groundwater Resources Program, FY 2010 challenge areas

Addressing Challenge Area 3: Monitoring effects of climate change on groundwater resources

Objectives: [1] Regional assessment of the likely sensitivity of groundwater to climate change in northern New England. This project will examine interannual correlations between the historical GW levels across northern New England (Maine, New Hampshire, and Vermont) and seasonal air temperatures and precipitation to define the sensitivity of GW levels to meteorological values by taking advantage of the large amount of interannual variability in northern New England climate. We will examine the interannual correlation of GW levels to hydrologic variables such as snowpack, snowmelt runoff timing, and seasonal streamflow and baseflow magnitudes to quantify the sensitivity of GW levels to other parts of the hydrologic cycle. Temporal trends will be computed for GW data with the longest records (25 to 50 years), to assess changes over time in GW resources. These trends would be put into a longer-term perspective by comparing them to previously computed hydroclimatic trends in northern New England.

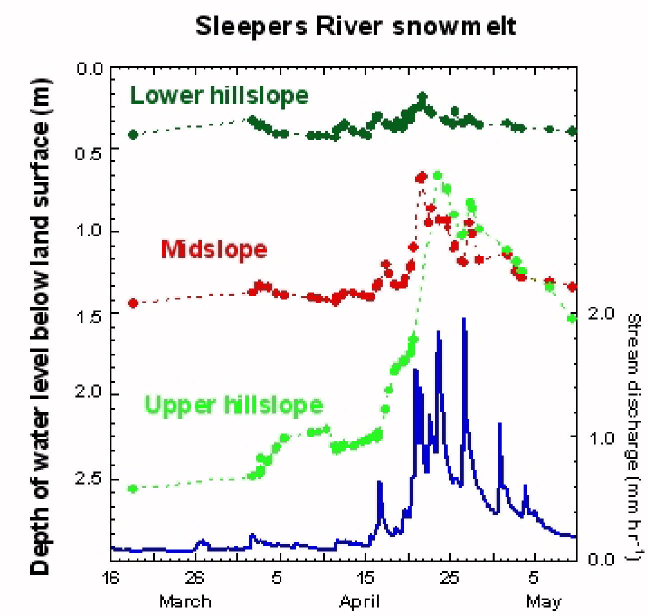

Figure 2 Snowmelt at Sleepers River showing stream hydrograph and groundwater response at three different hillslope positions Note that magnitude of response increases away from stream; increase in hydraulic gradient controls snowmelt recession, emphasizing importance of recharge to the uplands.

[2] Process-oriented assessment of the effects of changes in snowpack and frost on groundwater resources. Detailed GW records at Hubbard Brook and Sleepers River (fig. 2) will be examined with respect to snowpack depth and timing of melt; streamflows, particularly baseflows indicative of GW discharge; and climate data including air, ground temperature and frost depth to assess the effects of changes in snowpack and frost on GW recharge and storage. The annual snowmelt process will be assessed with respect to local watershed scale data to investigate seasonal and annual trends in GW resources. Variations in GW resources may be attributed to the timing of melt or the nature of that year's snowpack. Findings from the local scale process assessment will be provided to the regional GW assessment to help that component of the study investigate regional temporal trends.

Approach/Methods: Rob Dudley and Glenn Hodgkins will be the principal investigators for objective/task 1; Jamie Shanley and Tom Mack will be the principal investigators for objective/task 2. The correlations between GW data and other variables set forth in task 1 will include data from Hubbard Brook and Sleepers River to put these study areas into a northern New England framework. Process-related findings at Hubbard Brook and Sleepers River (task 2), will be used to inform the interpretation of the GW level correlations and trends across northern New England (task 1).

Task 1a: Regional assessment: Data assembly and quality-assurance (QA)

1. Retrieve all available GW metadata from NWIS for the study area. Preliminary screening of NWIS GW data shows about 90 wells in northern New England meeting minimum criteria of at

least 10 years of data. The median start year is 1976 with the earliest start year in 1943. The median number of tape downs is monthly (12 per year), ranging from as few as 6 per year to as high as 50 per year. Examine metadata and consult with GW specialists and data chiefs in the ME and NH/VT Water Science Centers to cull candidate sites on the basis of these criteria: Presence of substantial anthropogenic effects; minimum record length: 10 years for correlation work, 30 years for trend work; record completeness: no more than 5 missing years per decade for trend work (not necessary for correlation work); appropriateness of site in historical context: e.g. has the physical disposition of the site changed over time?

2. Retrieve all GW -level data from NWIS for remaining candidate sites and compute monthly GW -level changes for all available years– this will be the dependent variable of interest that will be used in all subsequent correlation and trend-testing analyses. Revisit record length and completeness criteria (above); cull sites as necessary. Compute seasonally aggregated data as appropriate on the basis of computed monthly changes
3. Retrieve monthly temperature and precipitation data from sites in the U.S. Historical Climatology Network (HCN) (Williams et al., 2007). The HCN was developed to assist in the detection of regional climate change and contains 1,221 stations in the contiguous United States. The HCN stations were chosen using multiple criteria including length of record, percentage of missing data, number of station moves and other station changes that may affect the data homogeneity, and spatial coverage. The quality of the HCN temperature and precipitation data was enhanced by use of outlier and areal edits, and the data were corrected for time of observation differences, instrument changes, instrument moves, station relocations, and urbanization effects (Karl et al., 1986; Karl and Williams, 1987). QA data on the basis of record length and completeness.
4. Assemble process-related hydrologic time series to be used for correlation analyses. These data sets describe other parts of the hydrologic cycle and will inform observed GW -level changes. These data have been quality assured as part of our previous work, thus saving much time and effort for the current project. They include: Snowpack depth, density, and water equivalent (Hodgkins and Dudley, 2006b); Timing of winter-spring snowmelt runoff – winter-spring center-volume date (WSCVD) (Hodgkins and Dudley, 2006a); Monthly streamflow magnitudes (Hodgkins and Dudley, 2005); Monthly baseflow magnitudes, and 7-day summer low baseflow (derived using HYSEP, Hodgkins and Dudley, 2009); Lake ice out dates: while not process-related, this variable will be included as it relates closely with variables listed above and, more importantly, it is the longest-term hydrologic data available in the northeast, with data for some lakes going back as far as the early 1800's (Hodgkins, 2009).

Task 1b: Correlation analysis

1. Perform correlation tests of monthly GW-level changes with meteorological and hydrologic time series noted above. As part of this analysis, we will investigate possible aggregation and (or) time-lag of explanatory variables.

Task 1c: Trend testing analysis

1. Test for bias in GW -level measurement dates over time
2. Compute trends for data series ≥ 25 yrs in length. Place GW trends results into a longer-term perspective (Task 1a4) and interpret results in context of process-oriented findings (Task 2b, c).

Task 2a: Process-oriented assessment: Data assembly and quality-assurance

1. At the Hubbard Brook Experimental Forest there are approximately 64 wells with weekly GW level measurements from 1979 to present. We will evaluate the quality of record and well locations with respect to hydrologic setting and stream gages. Adjacent to Hubbard Brook is the site of the Mirror Lake Fractured Rock Research project, where GW levels were continuously recorded since 1991. We will cull wells from this project that were not true water table level wells (i.e. they isolated fractures using well packers). We will assess these records and select a subset of the wells that have long-term quality water-level data which can be compiled and processed within the scope of this investigation. At Sleepers River there are 40 wells that have monthly GW level readings from 1991 to present. Three of the 40 wells have continuously recorded GW levels from 1992 to present. We know from periodic assessments that these data are high quality, but they will be methodically quality assured by “truthing” the electronic record to the monthly manual readings. The result for the 2 research watersheds will be more than 20 years of spatially distributed weekly to monthly readings supported by continuous record at discrete points.

Task 2b: Assess effects of snowpack and frost changes on groundwater

1. Snow accumulation and frozen ground development are climatic factors expected to change under global warming scenarios. Sleepers River and Hubbard Brook have some of the most complete long-term snow depth and water equivalent records in the Northeast, and some of the only frozen ground depth records in the Northeast. The two watersheds provide a range of hydroclimatic settings, prevalent in the glaciated northeast, which will be useful for identifying snowmelt processes. We will update our earlier analysis of the effect of snowpack and frozen ground on SW runoff (Shanley and Chalmers, 1999), and extend the analysis to the effects on GW levels. At the local scale, we will quantify direct connections between snowpack/ground frost and GW level fluctuations. Regionally, we will make at least a qualitative connection by extrapolating these relations to the broader regional GW patterns (Task 1), inferring snowpack development and likelihood of frost depth development from regional weather record analysis.

Task 2c: Local scale trend testing analysis

1. We will compute trends as above on the GW levels at Hubbard Brook and Sleepers River and evaluate them within the longer-term regional context (Task 1) to test for consistency of the headwater GW response with regional patterns.
2. To assess the effect of changes in upland snowmelt recharge on spring and summer low flow (fig. 2), we will evaluate trends in the snowmelt GW response (e.g. peak level, peak hydraulic gradient, computed downslope flow) with trends in the streamwater response (e.g. WSCVD). At Sleepers River we can incorporate past research on GW transmissivity and flow paths (Kendall et al., 1999; McGlynn et al., 1999; Shanley et al., 2003) in this analysis.

Products and Benefits: Study personnel will produce two peer-reviewed publications (journal articles and (or) USGS-series report), with accompanying factsheets, documenting data, methods, and results of the study. This study will contribute to understanding the sensitivity of GW resources to climate change in the snowmelt-dominated hydrologic system of northern New England. This study also will demonstrate the importance of maintaining a large, distributed network of USGS GW wells to contribute to understanding and monitoring climate change impacts on groundwater resources. The study will help identify regional data gaps and encourage cooperative funding of GW monitoring by more explicitly demonstrating the value of such data. For example, there is a strong possibility of future cooperative funding from NOAA, NMFS, USFWS, and the State of Maine for adding GW wells because of the importance of GW contribution to streams that are home to endangered Atlantic salmon. Similarly, the State of New Hampshire is currently evaluating adding wells to its network because it acknowledges the importance of the regions limited GW resources and the potential for impact due to climate changes. The study design for this project idea, after testing and refinement in northern New England, could be used in other areas of the U.S. where hydrology is similarly dominated by snowmelt.

Budget: Total funding of $300,000 over three years will be used to fund salaries of personnel (below).

	2010	**2011**	**2012**	**Total**
ME WSC	50,000	50,000	50,000	150,000
NH/VT WSC	50,000	50,000	50,000	150,000
Total	100,000	100,000	100,000	300,000

Personnel: Robert W. Dudley, Hydrologist, ME WSC; Glenn A. Hodgkins, Hydrologist, ME WSC; Thomas J. Mack, Hydrologist, NH/VT WSC; James B. Shanley, Research Hydrologist, NH/VT WSC

References Cited:

Hodgkins, G. A., and Dudley, R. W., 2006a, Changes in the timing of winter–spring streamflows in eastern North America, 1913–2002, Geophysical Research Letters 33: L06402, doi 10.1029/2005GL025593

Hodgkins, G. A., and Dudley, R. W., 2006b, Changes in late-winter snowpack depth, water equivalent, and density in Maine, 1926-2004, Hydrological Processes 20: 741-751

Hodgkins, G. A., 2009, Lake ice-out trends in New England, 1834-2008, Journal of Climate, in review.

Hodgkins, G. A., and Dudley, R. W., 2005, Changes in the magnitude of annual and monthly streamflows in New England, 1902-2002: U. S. Geological Survey Scientific Investigations Report 2005-5135, 37 p.

Hodgkins, G. A., and Dudley, R. W., 2009, Historical summer baseflow trends for New England rivers, Journal of Hydrology, in review.

Hodgkins, G.A., Lent, R. M., Dudley, R. W., and Schalk, C. W., 2009, Framework for a U. S. Geological Survey Hydrologic Climate-Response Program in Maine: U.S. Geological Survey Open-File Report 2009-1115, 24 p.

Karl, T.R., Williams, C.N. Jr., 1987. An approach to adjusting climatological time series for discontinuous inhomogeneities. J. Clim. Appl. Meteorol. 26, 1744-1763.

Karl, T.R., Williams, C.N. Jr., Young, P.J., Wendland, W.M., 1986. A model to estimate the time of observation bias associated with monthly mean maximum, minimum and mean temperatures for the United States. J. Clim. Appl. Meteorol. 25, 145-160.

Kendall, K.A., J.B. Shanley, and J.J. McDonnell, 1999. A hydrometric and geochemical approach to testing the transmissivity feedback hypothesis during snowmelt. Journal of Hydrology, 219, 188-205.

Mack, T.J., 2009, Assessment of ground-water resources in the Seacoast region of New Hampshire: U.S. Geological Survey Scientific Investigations Report 2008–5222, 188 p., available online at http://pubs.usgs.gov/sir/2008/5222.

McGlynn, B.L., J.J. McDonnell, J.B. Shanley, and C. Kendall, 1999. Riparian zone flowpath dynamics in a small headwater catchment. Journal of Hydrology, 222, 75-92.

Shanley, J.B., K.N. Hjerdt, J.J. McDonnell, and C. Kendall. 2003. Shallow water table fluctuations in relation to soil penetration resistance. Ground Water, 41(7), 964-972.

Shanley, J.B.and A. Chalmers, 1999. The effect of frozen soil on snowmelt runoff at Sleepers River, Vermont. Hydrological Processes, 13, 1843-1857

Williams, C.N. Jr., Menne, M.J., Vose, R.S., Easterling, D.R., 2007. United States Historical Climatology Network Monthly Temperature and Precipitation Data. ORNL/CDIAC-118, NDP-019, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.