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MANAGING FOREST HYDROLOGY RESEARCH – LESSONS FROM EXPERIMENTAL FORESTS IN THE USA

SANDRA ROBERTS

2009 GOTTSTEIN FELLOWSHIP REPORT

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Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

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Summary

I visited HJ Andrews LTER (Oregon), Coyote Creek Catchment Experiment (Oregon), Wind River Experimental Forest (Washington State), Coweeta Hydrologic Laboratory (North Carolina), and Hubbard Brook Long Term Ecological Research site (New Hampshire) during June and July 2009. I spent 4 weeks at Oregon State University processing and analysing 10 years of streamflow data from the Warra Long Term Ecological Research Site paired catchment experiments under the direction of Dr. Julia Jones (Geography department, Oregon State University). I also attended an Isotopes in Hydrology research workshop which coincided with my visit to OSU.

Before this trip I had taken the view that researchers are not always very good at identifying and designing research programs that provide useful results for land managers. This trip really highlighted the need for land managers to think about current and future management issues that may prevent the achievement of management objectives and to communicate clearly about these issues with researchers. At the same time it is important for researchers to spend the time that it takes to understand the operational and policy settings of natural resource managers so that their research projects can be designed to either produce useable information, tools and models, or information that will assist in the development of tools and models.

The USA Experimental Forest researchers are far better at sharing their information than most Australian Forest Hydrology Researchers. This is largely because in the USA resources have been provided for data collection, processing, storage, and web development to allow online access to data sets. Australian researchers would benefit if the importance of providing resources for data management and sharing were recognised and made more available.

The variety and type of streamflow gauging structures that I observed in the USA are probably of very little interest to a non-hydrologist, but to someone who is running a paired catchment experiment, being able to compare designs, learn about maintenance and data collection protocols, learn about the rating curve development and checking will lead to significant improvements in the way that our streamflow data is collected and certainly lead to a far more considered gauging structure design in the event that I am ever able to establish a paired catchment experiment in the future.

The Summer Synoptic Sampling program at Coweeta is a great example of interdisciplinary research. This program draws together chemists, geologists, hydrologists, biologists, and social scientists to describe the condition of streams, aquatic communities, social context and quality of water across a broad landscape. The methods used are a great way to get a snapshot of river condition, and by repeating the measurements twice for an extended period, a great way to understand how river condition is changing through time. A similar program would produce useful information for natural resource managers in Australia.

The Author

Dr. Sandra Roberts is a research officer with Forestry Tasmania. She has worked in forest hydrology research for 9 years since completing her PhD at the University of Melbourne with the Cooperative Research Centre for Catchment Hydrology. Sandra worked with NSW State Forests from 2001-2004 assessing the water use of eucalypt plantations in dryland salinity prone regions of NSW. Since 2004 she has been a Research Officer with Forestry Tasmania where her primary responsibilities are researching water use of plantations, streamflow in native forests, and water quality in native forests and plantations.

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Introduction

"To rule the mountains is to rule the rivers" (French Proverb)

Australia has 149 million hectares of forests comprising 147.4 million hectares of native forests and 1.97 million hectares of plantations. These forests cover about 19 per cent of the continent (Department of Agriculture Fisheries and Forests), and as such cover a large part of Australia's catchment area. It is important that forest managers are able to minimise their impact on water resources or take catchment management objectives (where they have been defined) into consideration during forest operations. Therefore it is important for forest managers to understand how their actions, natural events, and events such as climate change will influence forest structure, water yield, water quality and aquatic ecosystems.

Forest Hydrology is a relatively new science in Australia, with most studies into the effects of forests on water quality and quantity commencing in the 20th century. Paired catchment studies, where streamflow or water quality of a natural and treated catchment are compared to determine the impact of the treatment are a common way of studying the impacts of forest management on water resources. Australia's earliest forest hydrology paired catchment studies started in the Mountain Ash forests in Victoria after streamflow reductions were observed in routine streamflow records after fires in the 1920's. By the end of the 20th century paired catchment studies were established in forests in most states of Australia to explore the impacts of forest management on water resources – some examples (and a far from exhaustive list) are:

- Tasmania - Warra LTER (Ringrose and Meyer, 2001),
- Victoria - Cropper Creek (Bren and Papworth, 1991), North Maroondah (O'Shaughnessy et al., 1989), Coranderk (Nandakumar, 1993), Stewarts Creek (Nandakumar, 1993), Reefton (Nandakumar, 1993),
- NSW - Karuah (Cornish, 1993: Cornish and Vertessy, 2001), Yambulla (Roberts, 2001), Tanatawangelo (Lane et al., 2001), and Lidsdale (Putuhena and Cordery, 2000),
- WA - Collie River Basin (Ruprecht et al., 1991)
- QLD – Babinda (Cassells et al., 1982)

Figure 1. Warra Creek – example of a 120^o V-notch Weir used to gauge streamflow in a forest

While paired catchment experiments are an excellent way of quantifying the impacts of forest management on water yield or quality, they require considerable resources and a long-term commitment. In recent times there has been a move away from paired catchment studies towards shorter-term water balance studies (Putuhena and Cordery 1996), eco-physiology studies (Vertessy et al 1995; O'Sullivan, 1999; O'Grady et al., 1999), or targeted studies such as rainfall simulation studies (Sheridan et al., 2008;) to examine the effects of forest management on water resources.

Despite the many short-term and paired catchment experiments there is still much that is unknown about the impacts of forest management on water resources. New questions about the impacts of forest management on water resources continually arise in response to changes in community expectations, increased awareness of the need to protect aquatic ecosystems, prolonged drought, climate change, increasing competition for water resources, and the introduction of new legislation such as the National Water Initiative. As a result, forest hydrology remains a very topical area of research in Australia, as does the need for knowledge and tools that better enable forest owners to manage the impacts of their operations on water resources.

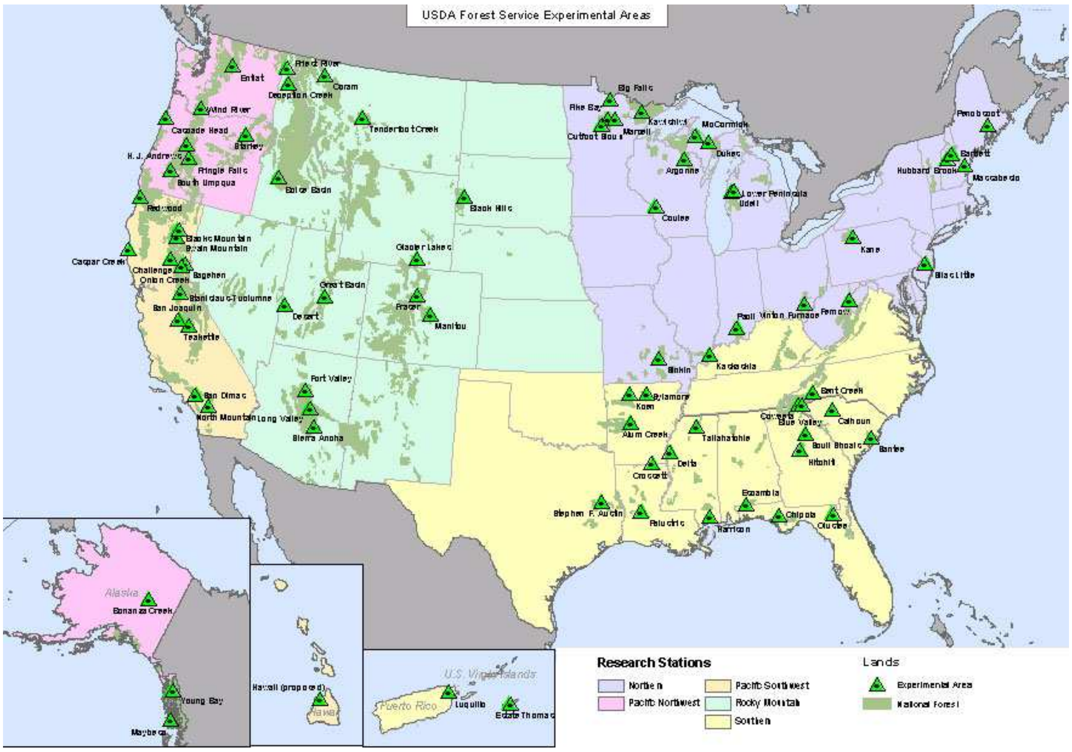

Figure 2. Map of USDA Experimental Forests and Ranges

The USDA Forest Service established more than 100 experimental forests and ranges during the last century (Figure 2). Although some of these experimental sites have served their purpose and have been decommissioned, 77 remain. Each experimental forests was established with a particular research focus, and for some of these forests and ranges, the primary purpose is hydrologic research. Watershed focussed experimental forests include:

- Marcell (Minnesota) – effect of timber harvesting on water quality and quantity
- <u>HJ Andrews (Oregon) – aquatic ecology, commercial logging impacts on water quality and quantity</u>
- <u>Coweeta (North Carolina) aquatic ecology, commercial logging impacts on water quality and quantity</u>
- <u>Hubbard Brook (New Hampshire) – forest harvesting, biogeochemistry</u>
- Caspar Creek (California) – impacts or harvesting and roading on water quality and flow

Research in USA experimental forests has significantly influenced public policy and forest practice law in the USA and continues to do so. The same can be said for research in Australian forests. However, because of the number and longevity of hydrologic studies in the USA, there is much for Australian researchers to learn from the research that has been undertaken and is in progress in USA Experimental Forests.

The Gottstein Fellowship enabled me to visit five experimental forests in the USA, to attend 4 Annual Science Meetings, and to interact with scientists undertaking research in these forests. I learnt about:

- a selection of hydrological and forest management issues in the USA
- the design and management of paired catchment experiments for quantifying the impacts of natural and man made activities
- communication and community consultation processes
- data collection, transfer, distribution and storage methods
- the importance of sample storage
- the summer synoptic sampling program at Coweeta
- the difficulties of maintaining long term research programs
- the use of stable isotopes in hydrological studies
- aquatic species management and impacts
- landslides and sediment movement.

I was also able to spend 4 weeks at Oregon State University analysing data from the Warra Long Term Ecological Research Site Hydrology Experiment under the supervision of Dr. Julia Jones. This report describes observations made on my journey in the USA.

Warra LTER Streamflow Data Analysis

Forestry Tasmania commenced hydrology research in the 1990's with studies into the movement of sediments from forested, harvested, burnt and agricultural land in North Eastern Tasmania. These studies demonstrated the relative sediment inputs of different land uses (Thompson and Wallbrink, 2002; Thompson and Wallbrink, 2002A; Thompson et al., 2002).

In the early 1990's, research expanded into methods for monitoring and managing offsite movement of silvicultural chemicals (Elliot and Hodgson, 2004). This occurred in response to concerns that silvicultural chemicals were contaminating drinking water supplies. Studies into assessing and managing the risk of offsite movement of silvicultural chemicals and monitoring methods are ongoing. In 2008 a new tool (the Pesticide Impact Rating Index) was developed for managing the risk of off site movement of silvicultural chemicals and is now used to assess and inform all Forestry Tasmania spray operations before they occur (Kookana and Correll, 2008; Volker and Trainer, 2008). In 2006 studies of plantation water use commenced with a view to developing the capacity in Forestry Tasmania's Forest Estate Model to predict the water use of plantations from plantation growth parameters estimated by the Forest Estate Model (Roberts and Barton-Johnson, 2009).

In 1998, Forestry Tasmania established a multiple catchment experiment, and numerous water quality monitoring sites in the Warra LTER to begin understanding hydrological processes in mature, pristine forests and the impacts of disturbances such as harvesting and fire on these processes (Bren, 1997; Ringrose and Meyer, 2001; Roberts, 2009). Managing this project is one of my responsibilities. The Warra project initially focussed on data collection, but is mature enough now for analysis of the data to take a higher priority.

The Gottstein Fellowship enable me to spend 4 weeks at Oregon State University in Corvallis, Oregon under the supervision of Dr. Julila Jones, checking and correcting stage height data, converting these to streamflow with the existing rating curves (with the assistance of Chris Livingston from Hydro Tasmania), and undertaking a preliminary analysis of the data. The results of the preliminary data analysis are reported in this section.

Figure 3. Student Union, Oregon State University, Corvallis

Streamflow gauging commenced in three streams in the Warra LTER in August 1998 and is ongoing. Streamflow monitoring is occurring:

a) to provide an understanding of seasonal and annual streamflow in Tall wet eucalyptus forests in Tasmania,
b) to better understand rainfall/runoff responses,
c) to enable comparison to hydrology in other forest types,
d) to identify any changes that may be occurring in streamflow through time due to natural or anthropogenic causes
e) to provide information that will enable forest managers to minimise the impacts of forest operations on streamflow.

The streams are all tributaries of the Warra Creek, which flows into the Huon River in southern Tasmania. The stream gauging stations are called Warra (442 ha catchment), Swanson (84 ha catchment) and King (48 ha catchment). The catchments are adjacent to each other, not nested (Figure 4)

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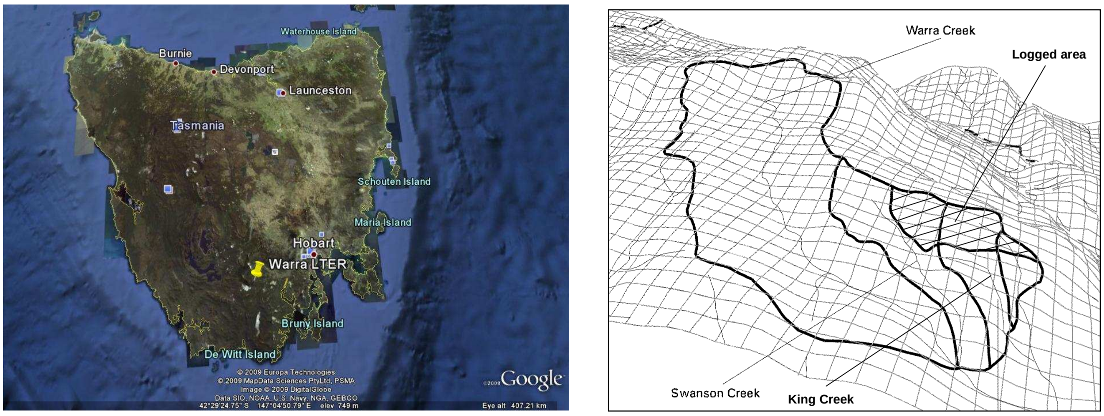

Figure 4. Map of Tasmania showing location of Warra LTER (GoogleMaps), and map of gauged catchments (Ringrose and Meyer, 2001)

The catchments are forested with *Eucalyptus obliqua* tall wet forest with a dense understorey of wet sclerophyll species. Geology is primarily Jurassic dolerite, with a small area of Permian sandstone occurring in King catchment (Ringrose and Meyer, 2001). Part of the area of Swanson (20 ha) and King (22ha) catchments was harvested in 1996 – prior to the installation of the stream gauging stations.

Figure 5. 120 degree v-notch weir and instrument shed at Warra Creek, showing typical riparian vegetation

Streamflow was measured with 120 degree v-notch weirs that were fitted to broad crested weirs. The steepness of the streams, the small size of the stilling ponds, and concern about approach velocity meant that the standard rating curves were checked against actual measurements of stage height and flow (Hydro Tasmania). There were differences between the standard rating curves and the measured flows, so new rating curves were developed by Hydro Tasmania. Streamflow volume measurements were made at three flow levels using either a bucket to catch the output from the v-notch during a timed period, or flow meter to estimate water velocity in combination with stream cross sectional area. The rating curves require further improvement, particularly during peak flows. It is important to note that improvement of the rating curves in the future may mean that future reports on streamflow produce different estimates from this report.

Stage height was recorded at 5 minute intervals using UNIDATA Starlogger dataloggers and UNIDATA water level instruments. The dataloggers were downloaded at 2 – 4 weekly intervals.

Forestry Tasmania established weather stations at Warra Rd (2001) and Manuka Rd (1998) to record rainfall, temperature, solar radiation and relative humdity. These were largely unsuccessful at collecting data due to technical difficulties. The Bureau of Meteorology established a weather station at Warra Rd in 2005 and good quality weather data is available from this time.

There have been several significant difficulties with streamflow data collection that need to be taken into consideration during data processing and analysis.

a) Calibration and resetting of the water level float recorder. Instead of measuring the height of water in the pond near the float, early technicians used the height of water flowing through the notch to set the float recorder. This is incorrect as the water forms a depression at the notch, which leads to a variable underestimate of the water level in the pond. We formed a regression between pond height and notch height over a 2 year period and used this to correct every individual stage level record for the first 7 years of the project.

b) King weir leak. A leak occurs at King Weir just below the structure. We built a small weir and measured the leak at intervals to see if it was related to the height of water in the stream so that it could be predicted based on stage height. Leak volume was not related to stage height. It appears to be linked to catchment wetness indicating that this could be groundwater seepage escaping from around and below the weir rather than leakage from the weir. If there is significant loss of groundwater from any or all of the catchments then this could lead to an underestimate of the streamflow from the catchment.

c) Rating curves. The lack of stream ratings for the full range of flow means that the rating curves used to convert stage height to streamflow have significant room for improvement.

d) Missing data. There have been significant losses of stage height data during the ten years of measurement due to failure of instrumentation, the necessity to drain the weirs to service water quality instruments (due to their installation in an inaccessible location in the weirs), and due to technician error and software failure (Table 1, tabulates the days of missing data at each of the weirs during each year).

e) Weather data. Rainfall data for the first 5-6 years of the study is unreliable despite the installation of 2 automatic weather stations and is excluded from analyses.

Results

Streamflow data collected from August 1998 to March 2009 are analysed in this report. Stage height readings collected at 5 minute intervals were collated in a single database, defective readings were identified and removed from the records (Hydro Tasmania). Stage heights were corrected for the difference between water level at the notch and at the pond, then were transformed to estimates of streamflow using the rating curves developed by Hydro Tasmania. Data were amalgamated to give daily estimates of streamflow for each of the sites (Figure 6).

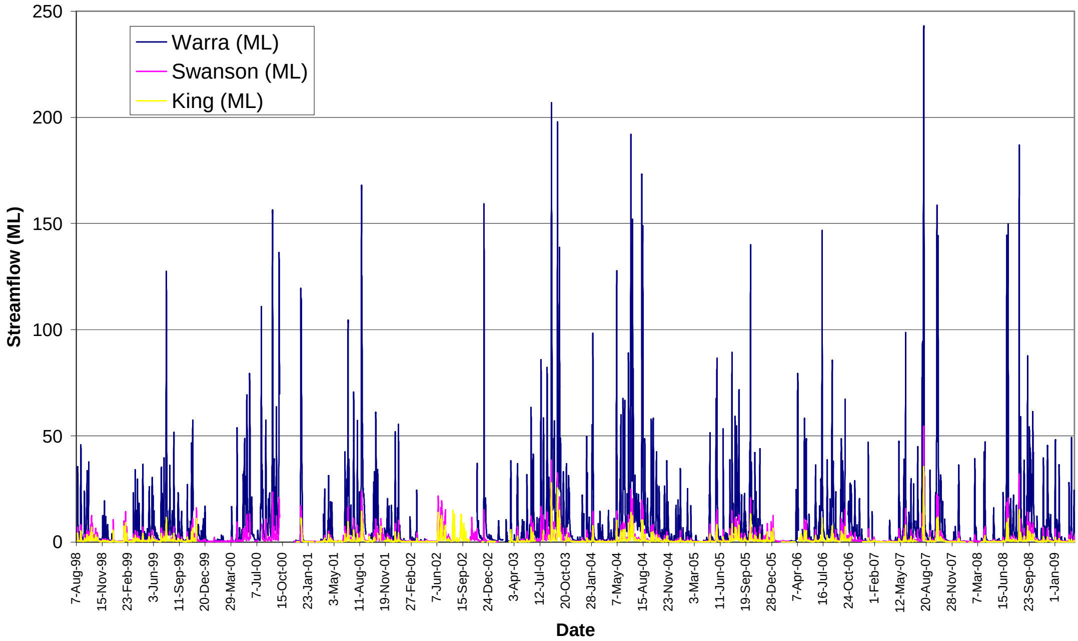

Figure 6. Daily streamflow (ML) for Warra, Swanson and King Creeks from August 1998 to March 2009.

Table 1. Number of days and percentage of streamflow data available for each year for each site. Note that 1998 and 2009 records did not span an entire year.

	Number of days with record			Percent of days with record		
Year	Warra	Swanson	King	Warra	Swanson	King
1998	100	147	147	27	40	40
1999	301	343	321	82	94	88
2000	267	281	18	73	77	5
2001	229	341	323	63	93	88
2002	167	294	304	46	81	83
2003	357	301	256	98	82	70
2004	366	366	366	100	100	100
2005	310	345	365	85	95	100
2006	286	254	275	78	70	75
2007	303	355	343	83	97	94
2008	366	366	318	100	100	87
2009	77	77	77	21	21	21

Because estimates of annual runoff are desired, gaps in the daily data set were filled by regression with the other sites. This is less than ideal particularly as we wish to evaluate the sites for differences through time, and is certainly not ideal in years when large amounts of data are missing (eg. King Creek 2000), but is unavoidable.

I evaluated the relationships between daily streamflow at each of the sites to determine the best way to fill gaps in the streamflow records. Even when data were transformed to improve normality and homoscedacity, data were not linearly related between sites. Consequently either 3 or 4 separate relationships were identified for different flow levels between each of the sites (Figure 7) and applied to fill gaps. There were very few days for which there were no records available from any of the sites (5/10/00-28/11/00, 12/10/02, 19/2/03-26/2/03, 12/4/06). In these instances, streamflow was estimated as the average of the flows on either side of the gap.

Summary statistics were calculated for the filled daily streamflow (mm) records using Microsoft Excel (Table 2)

Table 2. Summary statistics for daily streamflow (mm) in three streams in the Warra LTER.

Runoff (mm/day)	Warra	Swanson	King
Mean	2.26	2.00	1.83
Standard Error	0.07	0.06	0.06
Median	0.65	0.74	0.73
Mode	1.04	1.72	1.30
Standard Deviation	4.61	3.90	4.00
Sample Variance	21.24	15.21	15.96
Kurtosis	29.40	45.58	71.83
Skewness	4.68	5.34	6.70
Range	54.60	64.42	73.06
Minimum	0.02	0.11	0.02
Maximum	54.62	64.53	73.08
Sum	8769.08	7762.66	7079.30
Count	3877	3877	3877

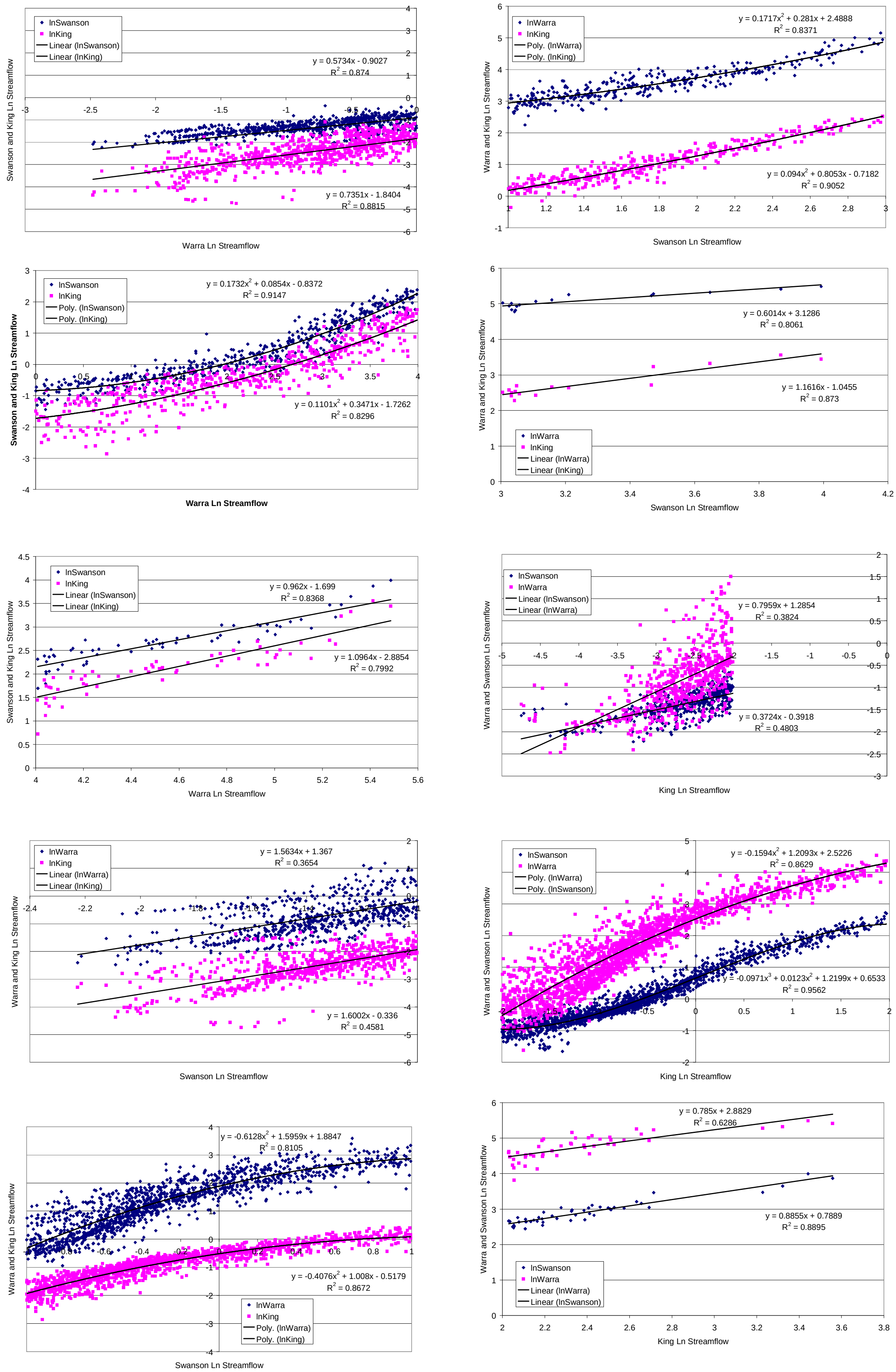

Figure 7. Regression relationships

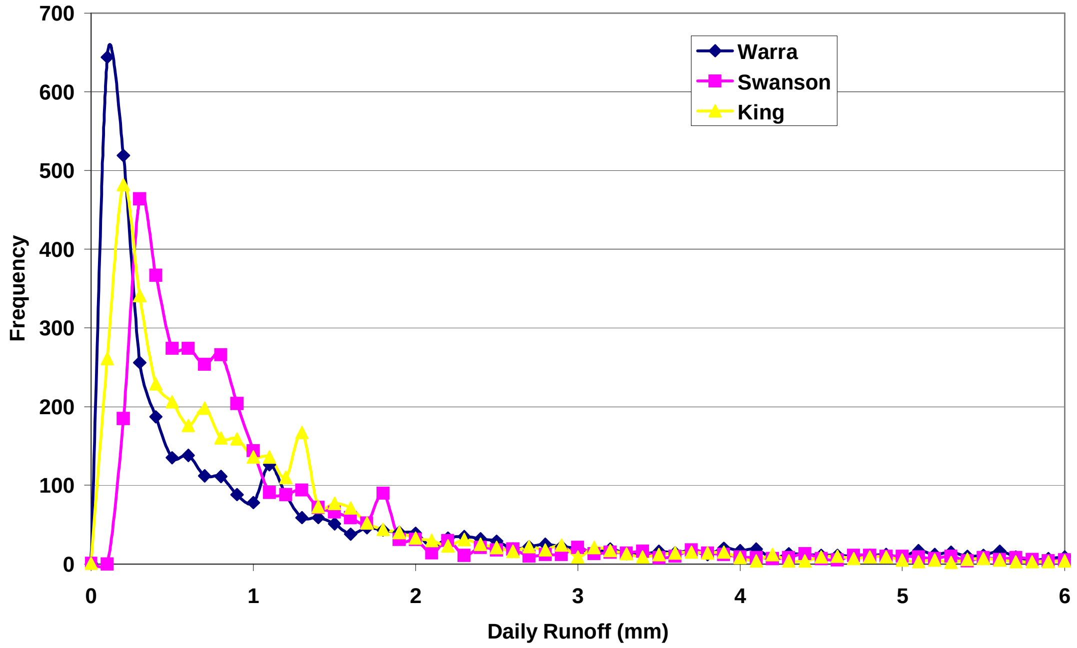

Figure 8. Frequency distributions for daily values

Figure 8 illustrates the frequency distribution of daily streamflow in each of the catchments. The majority of flow is less than 2 mm per day. Table 3 lists the estimated annual streamflow for each of the catchments, rainfall at Warra Rd (red numbers are numbers that are incomplete estimates for the year), and runoff:rainfall ratios for each of the catchments. Figure 9 illustrates the annual runoff and runoff:rainfall data from Table 3. Warra typically generates slightly more runoff than Swanson or King, but no statistical analyses have been performed to see if these differences are significant.

Table 3. Mean annual values for filled data sets.

	Streamflow (ML)			Streamflow (mm)			Rainfall	Runoff:Rainfall Ratio		
Year	Warra	Swanson	King	Warra	Swanson	King	(mm)	Warra	Swanson	King
1998	1419	240	130	321	285	272	1554.854			
1999	2793	489	295	632	582	615	1311.422			
2000	3660	659	320	828	784	667	1527.036			
2001	3251	563	304	736	671	633	1644.314			
2002	4946	805	437	1119	959	911	1988.42			
2003	3991	731	378	903	870	787	1398.614			
2004	5365	656	379	1214	780	789	1840.272			
2005	3243	584	294	734	695	613	2356.2	31.13913	29.49944	25.99526
2006	3361	614	302	760	731	630	2186.6	34.778	33.44891	28.80624
2007	3363	609	299	761	725	623	2161.2	35.20546	33.54252	28.82973
2008	2975	512	239	673	609	498	2095.6	32.11995	29.08234	23.74677
2009	389	58	19	88	69	40				

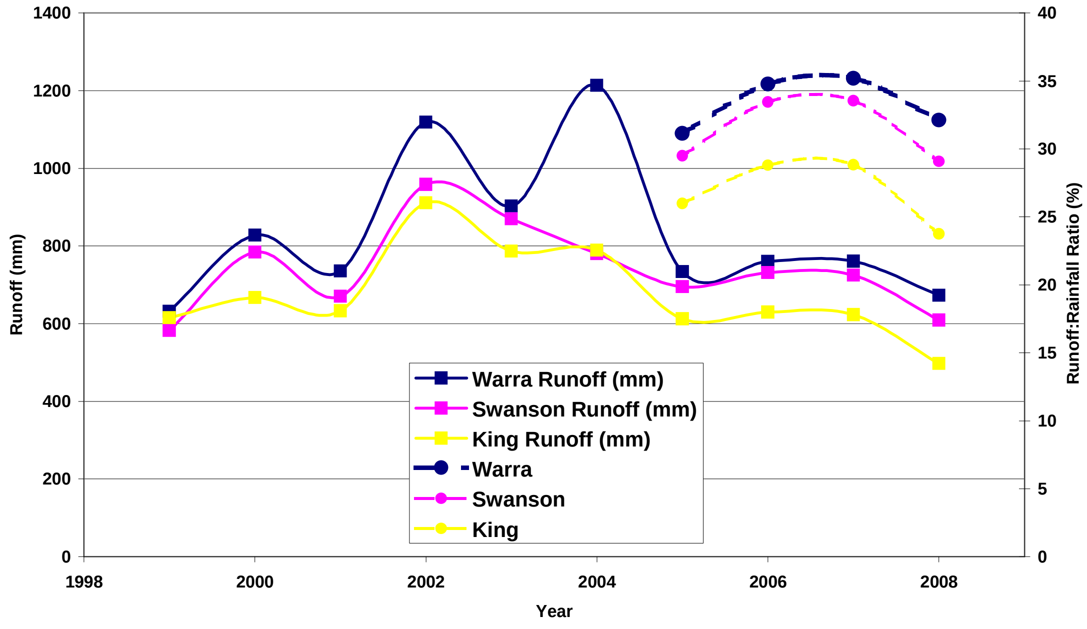

Figure 9. Annual Runoff (mm) and Runoff:Rainfall ratios (%)for each of the catchments

Table 4. Seasonal streamflow for Warra, Swanson and King Creeks

Season	Streamflow (ML)			Streamflow (mm)		
	Warra	Swanson	King	Warra	Swanson	King
Winter 1998	180	36	22	41	43	46
Spring 1998	1104	176	94	250	209	196
Summer 98/99	486	97	53	110	115	111
Autumn 1999	584	109	65	132	130	134
Winter 1999	1007	163	104	228	194	216
Spring 1999	741	132	78	168	157	162
Summer 99/00	166	34	17	37	40	36
Autumn 2000	617	113	49	140	135	102
Winter 2000	1086	177	84	246	211	176
Spring 2000	1398	271	127	316	322	265
Summer 00/01	529	93	59	120	111	122
Autumn 2001	256	51	29	58	61	60
Winter 2001	1829	305	167	414	363	347
Spring 2001	961	162	84	217	192	176
Summer 01/02	388	81	39	88	97	82
Autumn 2002	99	34	11	22	41	22
Winter 2002	2399	387	218	543	461	454
Spring 2002	1888	298	159	427	354	332
Summer 02/03	424	57	39	96	67	80
Autumn 2003	361	79	38	82	94	78
Winter 2003	1655	316	154	375	377	322
Spring 2003	1819	304	171	411	362	357
Summer 03/04	626	78	34	142	93	72
Autumn 2004	828	97	59	187	115	123
Winter 2004	2917	359	214	660	428	447
Spring 2004	984	120	70	223	143	145
Summer 04/05	367	55	22	83	66	46
Autumn 2005	461	91	41	104	108	85
Winter 2005	1120	209	112	253	249	234
Spring 2005	978	176	94	221	209	195
Summer 05/06	645	115	51	146	137	106
Autumn 2006	893	164	81	202	195	168
Winter 2006	1096	177	102	248	211	212
Spring 2006	1065	209	93	241	249	194
Summer 06/07	240	46	21	54	55	44
Autumn 2007	316	57	19	72	68	40
Winter 2007	1470	273	151	333	325	315
Spring 2007	1277	227	108	289	270	225
Summer 07/08	212	36	14	48	43	28
Autumn 2008	228	46	16	51	54	33
Winter 2008	1345	222	110	304	264	230
Spring 2008	1111	197	93	251	234	193
Summer 08/09	483	75	28	109	89	59
Autumn 2009	117	15	5	27	18	9

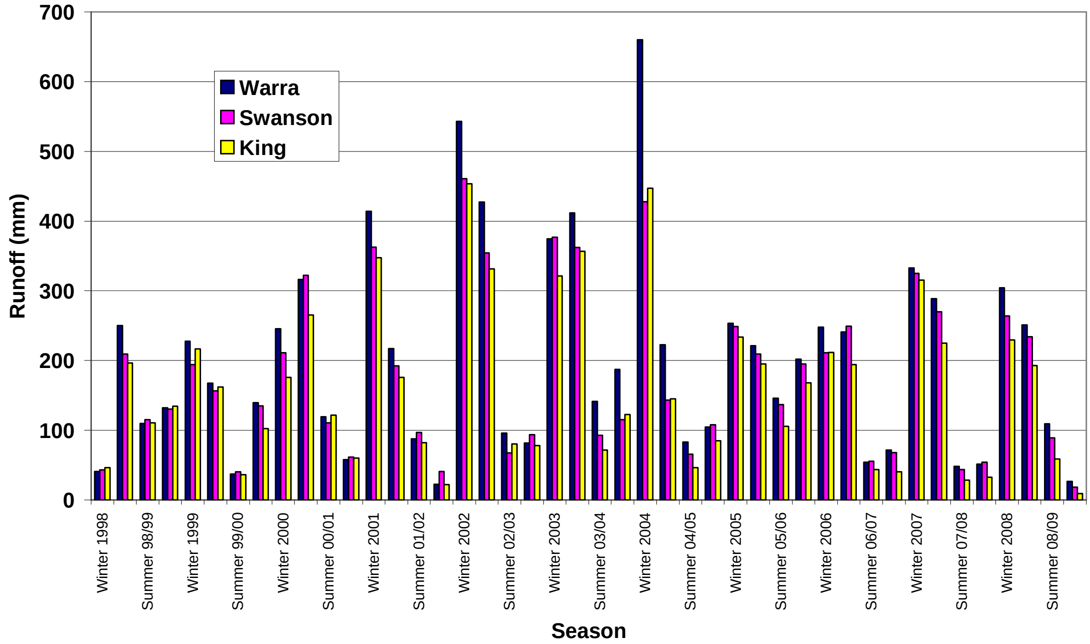

Figure 10. Chart showing seasonal streamflow volumes for each catchment for duration of the study

There is a seasonal peak in flow in winter/spring (Figure 10). Flow during these seasons is usually at least twice the flow observed in summer/autumn. More than 40% of rain occurring in Winter becomes streamflow while less than 20% of summer rainfall is converted to flow (Figure 11). This is to be expected, as evapotranspiration will be greater in summer and catchments will be drier and have greater capacity for storing and evaporating rainfall than a saturated catchment in winter.

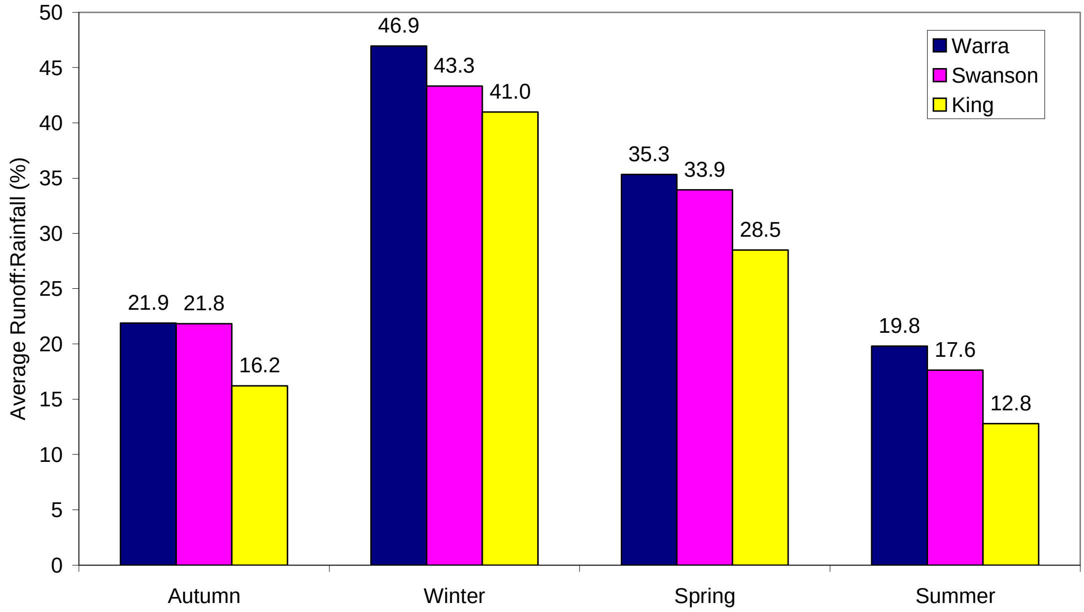

Figure 11. Average runoff ratio for each season

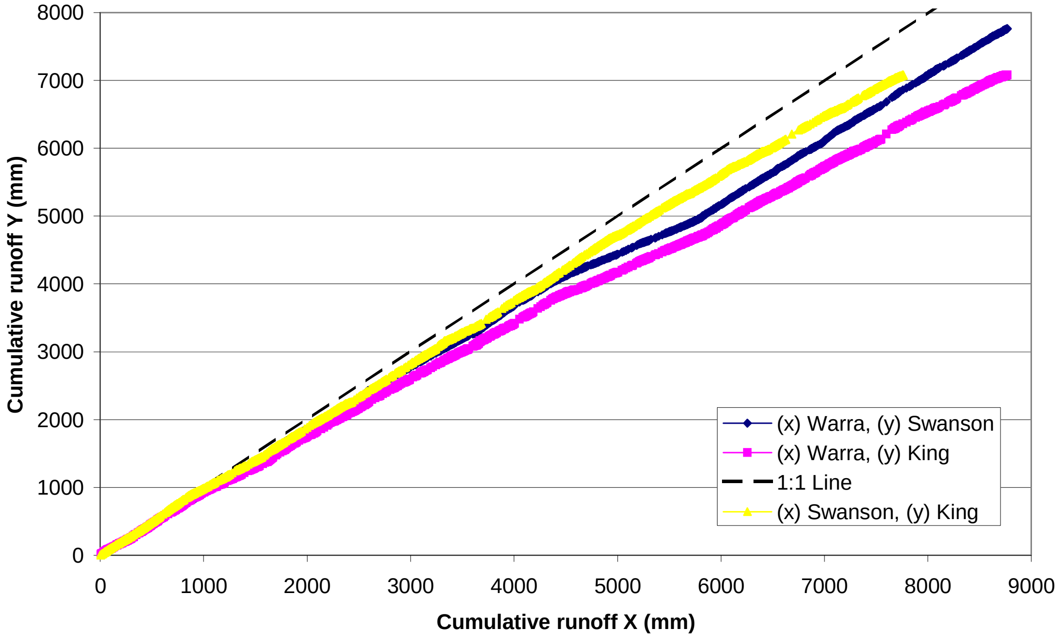

Figure 12. Double mass plots for daily values

Double mass plots (Figure 12) can be further evaluated to detect differences in relative runoff production in the three catchments through time. There appear to be inflections in the double mass plots that with further investigation may be shown to correspond with changes in catchment condition or changes in instrumentation or field protocols.

I used the River Analysis Package (CRC Catchment Hydrology Toolkit) to separate base flow from peak flow. Base flow is streamflow that results from slow percolation of rainfall through soil and bedrock, while peak flow is the streamflow that occurs in almost immediate response to rainfall. Peak flow either directly enters the stream, drains overland during rainfall or moves rapidly through shallow soil layers.

Mean base flow was estimated at 0.399, 0.465, and 0.418 mm/day for Warra, Swanson and King creeks respectively. This equates to 145.8, 169.9 and 152.8 mm/year. With total flow averaging 836, 741, 677 mm/year for Warra, Swanson and King Creeks respectively, this means that base flow accounts for 17, 23 and 22% of flow in Warra, Swanson and King Creeks respectively, with peak flow comprising 83, 77 and 78% of flow for each of the streams. It will be useful to compare different base flow separation techniques and to compare base flow in the Warra LTER with base flow in other regions.

Discussion and conclusions.

Travelling to Oregon was an excellent way to have uninterrupted time to work on the data set and this is the first time in 10 years that the data have been converted to streamflow and attempts have been made to fill gaps. The results presented here are preliminary and further analysis and presentation of the data is still required to improve our understanding of streamflow in these catchments, however, the data set is complete now and ready for further assessment.

Future work with the data set and experimental catchments may include:

- installation of more rain gauges to get a better understanding of rainfall variation in the catchments
- further refinement of rating curves, particularly at high flows
- comparison of stream flow at these sites with other sites in Australia and world wide
- comparison of streamflow data to water quality data

- further evaluation of double mass plots for inflections that may be due to changes in catchment characteristics
- consideration of the possible impacts of changed rainfall regimes due to climate change on seasonal and annual runoff
- an assessment of catchment characteristics such as size, shape, slope, vegetation type, geology, wetness index, to see which if any of these characteristics are likely to influence runoff processes in the three catchments
- use of streamflow estimates and rainfall to estimate evapotranspiration to form ET versus Forest Basal Area estimate for incorporation of results in Forest Estate Model for estimation of water use of native forests of this type

Experimental Forests and Ranges in the USA

Forestry research in the USA commonly occurs in United States Department of Agriculture (USDA) Forest Service Experimental Forests and Ranges. These are areas of land where research is identified as a key management objective. There are currently 77 Experimental Forests and Ranges with active research in the USA. Studies in Experimental Forests and Ranges have provided scientific information for the management of forests and lands in the USA for more than 100 years. These sites provide answers to questions concerning the impacts of management activities and natural disturbances, their mitigation and how to better achieve management goals. They serve as focal points for education and demonstration projects, and venues for interaction between scientists, land managers and for the training of graduate students (Crawford, RH, 'USDA Forest Service Experimental Forests and Ranges' brochure).

I visited 5 Experimental Forests during my visit to the USA. These were South Umpqua (Coyote Creek), Wind River, HJ Andrews, Coweeta and Hubbard Brook Experimental Forests (Figure 13). I was able to attend the HJ Andrews Annual Science Meeting, the Coweeta LTER Science Meeting, and Hubbard Brook Annual Meeting. This section of the paper describes my visit to each of the Experimental Forests.

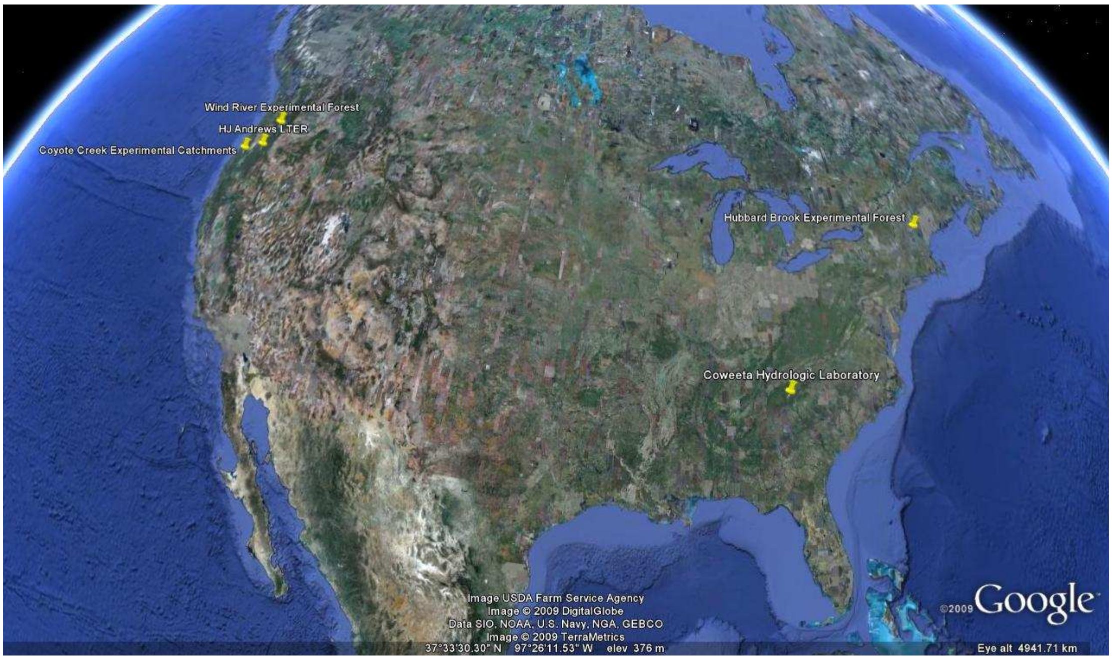

Figure 13. Location of USA Experimental Forests Visited

South Umpqua Experimental Forest (Coyote Creek Experimental Catchments) 11/6/2009

The South Umpqua Experimental Forest is located in the Tiller Ranger District of the Umpqua National Forest. The Umpqua National Forest extends over almost 1 million hectares and is managed for timber, recreation (campgrounds and trails), and habitat (including the habitat of anadromous (sea going) fish such as Salmon) among other values.

Figure 14. Map of Umpqua National Forest in South-west corner of Oregon (http://www.fs.fed.us/r6/umpqua/maps/)

The Coyote Creek Research catchments in the Tiller Ranger District comprise a control catchment (Watershed 4), a shelterwood catchment (Watershed 1), a patchcut catchment (Watershed 2) and a clearcut catchment (Watershed 3). Streamflow has been gauged in the 4 watersheds since 1964. Harvesting in the three treated catchments occurred in 1971. The most recent paper on hydrology in the catchment was written by Jones (2000), and measurements of tree cover in the catchments were made by Arthur (2006). Streamflow monitoring has shown a short term increase in flow in the harvested catchments followed by a yield reduction as the forest regrows. Streamflow decreases due to forest regrowth are potentially of concern to downstream irrigators and there is a strong desire in the local community to maintain streamflow at levels that enable fish passage and spawning.

Michael Jones (District Hydrologist), Bob Nicholls, Paul Anderson, Roshanna Stone (Forest District Manager), Amy Rusk, Greg Downing (Field Technician – HJA), Deborah Graham, Fred Swanson (USDA Forest Service), Julia Jones (OSU), Stan Petrowski (Local catchment mangagement authority), Laurie Blackmore and Maureen Jocklin met to discuss the future of the Coyote Creek research catchments on 11/6/2009. Beyond the streamflow gauging, no additional measurements, analysis and interpretation of the data are occurring and no plans have been made for treatments in the catchments into the future.

The meeting involved a round table discussion and a tour of the catchments. Potential research topics were discussed and financial, silvicultural and biological benefits and impediments to the implementation of various research ideas were discussed.

Streamflow monitoring is ongoing in the 4 catchments, but needs to have a clearly defined purpose to justify the expense of data collection. It is possible that the purpose of the monitoring may be as simple as to allow the hydrologic characteristics of Coyote Creek catchments to be compared with the characteristics of other catchments, or it may be that more specific questions can be answered by the application of treatments (eg. non-commercial thinning with pyrolysis?) to the catchments or the collection of further data (stand surveys?). Research approaches need to be considered in the context of what is legal (eg. Sugar Pine cannot be harvested nor can old growth), what is possible (given the current condition of the catchments and the resources available) and what would be useful knowledge to obtain either for the local community, policy makers or forest managers.

We visited each of the catchments to view regrowth and to discuss possible ongoing treatments and measurements.

The control catchment (Catchment 4) comprises uncut old-growth forest. There is concern that the control catchment is not static and has changed substantially during course of experiment – for example there has been some windthrow and some development of the understorey since cattle grazing was excluded. Measurements of the overstorey and understorey type and density would help to describe these changes.

Watershed 1 was partially harvested in 1971 and is too young for a commercial thinning or harvesting and contains enough old growth elements that it may not be eligible for this. However thinning may be useful in this catchment to see if this abates the water yield deficits observed since the partial thinning operation. Thinning from below would be preferred. Local staff advised that there was no funding available for non-commercial thinning and that it may not even be possible given policies on harvesting of old growth forests. A suggestion was for on site fast pyrolysis to produce energy for a wood chipper and to produce oil for sale. Fast pyrolysis is a thermal process that rapidly heats woody biomass to a controlled temperature (500 degrees C) and then quickly cools the volatile products to yield: Bio-oil (60%), Bio-char (20%), and Syngas (20%). The syngas is recycled into the combustion chamber to keep pyrolysis going or it can be collected. The bio-oil and bio-char are collected and trucked offsite. If on site pyrolysis could be used to process l thinning residues and thinning costs were covered by oil sales, non-commercial thinning could potentially occur. It would have the advantage of processing residues on site so that nutrients are retained. However thinning even with pyrolysis was still not viewed favourably by local managers. Burning one of the catchments was suggested as another possible treatment. It was also suggested that engaging a graduate student to undertake stand surveys and to assess leaf area and basal area of stands in the catchments could be useful. The discussion continued as we toured catchments 2 and 3, which while also showing potential for thinning operations do not have the maturity for this to be financially viable.

No conclusions were reached on the day as to the best way forward with the research program, but I found the discussion informative. The informal discussion between the forest managers, silviculturists, planners, scientists, hydrologists and local catchment group highlighted that forest managers and the community need to better communicate their research requirements to the scientists and that scientists need to understand the policy and operational setting that the land managers are working in and the data and resources that are available. As a researcher working for a forestry organisation, I frequently encounter the results of very good research that will never be adopted by industry because the research was either poorly targeted, produced results or models that are in a format that is not compatible with management systems or tools, or produced models and tools that require a complex array of inputs or information that is simply not available at the scale that the forest managers operate at. Better communication between researchers and land managers should help to overcome some of these issues to enable greater use of research results in the management of forests and catchments.

H J Andrews Experimental Forest and LTER

The HJ Andrews Experimental Forest is situated in the western Cascade Range of Oregon in the 15,800-acre (6400-ha) drainage basin of Lookout Creek, a tributary of Blue River and the McKenzie River (Figure 15). Elevation ranges from 1350 feet (410 m) to 5340 feet (1630 m). HJ Andrews is broadly representative of the rugged mountainous landscape of the Pacific Northwest, and contains excellent examples of the region's conifer forests and associated wildlife and stream ecosystems.

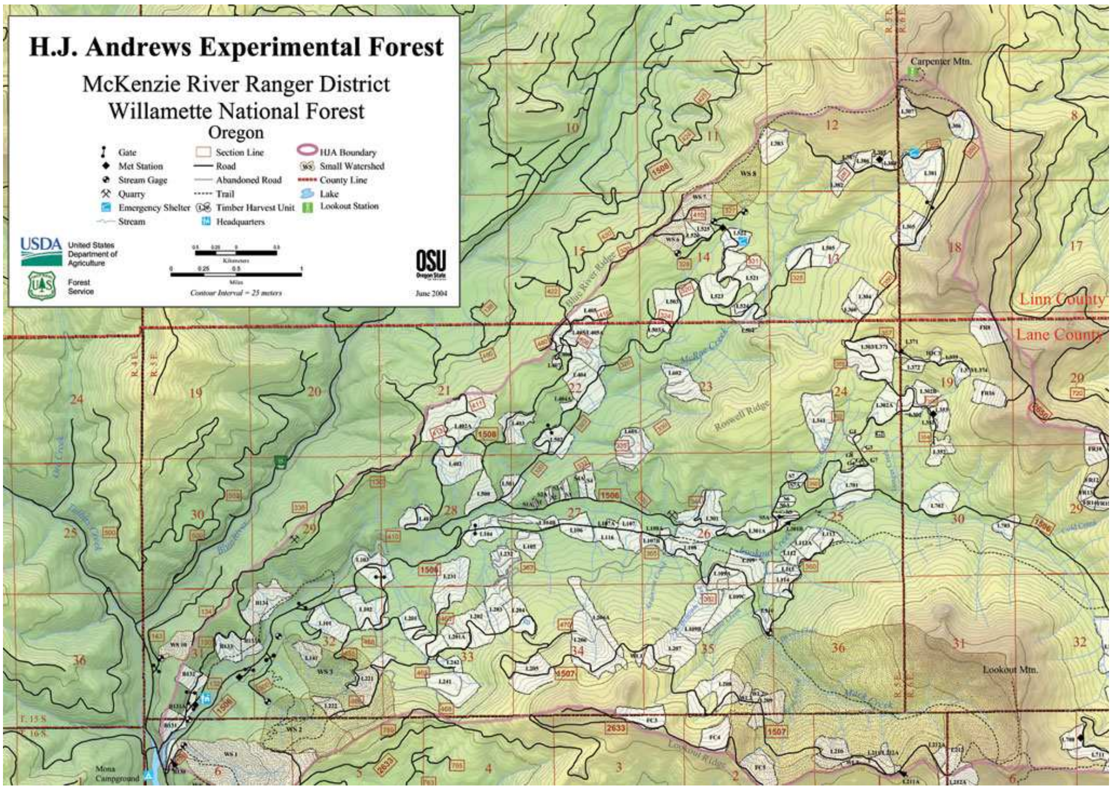

Figure 15. Map of HJ Andrews Experimental Forest

When HJ Andrews Experimental Forest was established in 1948, the Andrews was covered with virgin forest. Timber cutting began in 1950. Clearcutting and shelterwood cuttings over about 30% of the Andrews Forest have created young plantation forests varying in composition, stocking level, and age. Old-growth forest stands with dominant trees over 400 years old still cover about 40 percent of the total area. Historically, wildfire was the primary disturbance in the natural forest; windthrow, landslides, sites of concentrated root rot infection, and lateral stream channel erosion were secondary disturbances. Stands aged100 to 140 years old originating from wildfire cover about 20 percent.

The lower elevation forests are dominated by Douglas-fir, western hemlock, and western red cedar. Upper elevation forests contain noble fir, Pacific silver fir, Douglas-fir, and western hemlock. Low- and mid-elevation forests in this area are among the tallest and most productive in the world.

Figure 16. Example of old-growth forest in HJ Andrews Experimental Forest

Research in the 1950's centred on the impacts of road systems and harvest of old-growth forests on watersheds. Research in the 1960's focused on effects of logging on water, sediment, and nutrient losses from small watersheds. During the 1970's, studies centred on the structure and function of forest and stream ecosystems, particularly in old-growth forests. In the 1980's, these studies continued under LTER funding and were augmented with applied research in silviculture, wildlife, landscape ecology, and other topics. The central question currently guiding the Andrews Forest LTER studies is: How do land use (mainly forestry and roads), natural disturbances (mainly fire and floods), and climate change affect: carbon dynamics, biodiversity, and hydrology?.

I attended HJ Andrews Annual Science Meeting; spent a day looking at landslides with Fred Swanson; spent a day with the Hydrology technicians reinstalling a summer flow weir plate, checking rating curves, and looking at stream flow gauging equipment and management; met with a data manager to learn about data management, processing, storage and distribution.

HJ Andrews annual science meeting 17/6/2009

Each summer the HJ Andrews annual science meeting is an opportunity to bring researchers, students, forest managers, technicians, administrative staff, and members of the local community together to learn about the research program, tour the forest, generate discussion about projects and management and to enable networking amongst the participants. I was invited to attend the 2009 Annual Science Meeting.

After a brief welcome and introductions, participants inspected the weather monitoring station near the HJ Andrews Headquarters. Weather has been monitored at HJ Andrews since the 1970’s (from memory at about 6 locations). Air temperature, Relative Humidity, snow depth, wind speed, wind direction, soil temp, soil moisture at a range of depths, precipitation chemistry, snow pillow, atmospheric deposition, mercury deposition, solar radiation and rainfall are monitored. Equipment has been designed to cope with snow and below freezing conditions. A full time technician takes care of the weather stations, and an information manager handles the data that is retrieved from the stations. Data is retrieved from 4 of the weather stations each hour via telemetry so that the web page always presents the most up to date weather information.

We inspected a 40 year old plantation (Douglas fir forests do not regrow well naturally so if they are burnt or harvested the sites are usually replanted). Many of the plantations are denser than the old-growth stands that they replaced and consequently do not support the same organisms. Stem density may be actively managed so that regrowth forest structure becomes more like that of old-growth forests – techniques such as partial harvesting and thinning were discussed as well as natural processes such as bark beetle damage, root rot, competition and weather damage.

The original focus of studies in HJ Andrews was on growing trees for wood, with a move towards understanding ecosystem function, and old growth forest values in later years (Fred Swanson). In more recent times there has been a significant shift towards understanding the social values of forests, citizen attitudes (Brent Steel) and humanities studies (Kathleen Moore). Each year artists and authors are invited to HJ Andrews as part of the 'long term ecological reflections program' to record their observations (Larry Rogers). Developing a better understanding of community perceptions, knowledge and values helps researchers to develop better education programs, to better appreciate the non-wood values of forests and to think about forming links between science and humanities in their research programs.

Presentations were given at Watershed 1 by research Scientists - Barbara Bond, Tom Spies, Clare Phillips, Harold ?, Steve Le Duc, Kate Likar, Jeff McDonnell, Renee Brooks, Moore, and Mark Harmann. Watershed 1 contains mixed species regrowth forest (hardwoods and softwoods) and has been intensively studied for comparison with old-growth forests. Streamflow is gauged, water quality and nutrients are monitored, there is a carbon flux tower in the catchment, isotope studies and transpiration studies have been undertaken to understand water balance and streamflow generation processes, LIDAR data has been used to describe catchment characteristics including vegetation canopy cover and height, ground plots were measured to determine basal area, biomass, leaf area, habitat quality and forest structure and soil respiration and soil moisture have been measured to better understand carbon production.

Significant findings in Watershed 1 so far are that:

- increasing rotation length by 10-20 years will expand carbon storage,
- trees mostly use water that is strongly bound to soil (and not able to drain to streams) rather than water that is freely draining through soil pores so have less capacity to influence streamflows than previously thought
- the age of water in streams is approximately 2 years in Watershed 1 – water in soil and bedrock is not well mixed
- fluxes of carbon from forests are nearly as large as intake of carbon
- there is more carbon below ground than above it so fluxes of soil carbon are significant
- trees mostly access water from a depth of 20-40 cm based on xylem and twig isotope samples

Figure 17. Tom Spies, Barbara Bond and Kate Likars in Watershed 1

Further presentations were given at Lookout creek by Julia Jones, Sherri Johnson, Matt Belts, Sarah Fry and Allan Tepley. Lookout Creek is an old-growth forest and studies of phenolgy, the impact of climate change on phenology, ecosystem modelling, permanent plots, and tree ring analyses are conducted there. Phenology studies are designed to show if human or natural events are causing the timing of activities such as plant flowering, leaf fall, the arrival of migratory species, hatching of insect and bird species to change and if so, what the likely outcomes of altered timing of activities will be. For example, if deciduous trees grow foliage earlier in spring due to increasing temperatures will migratory birds that eat the caterpillars that eat the leaves arrive too late for their usual spring feast? Tree ring studies from 3400 tree cores over 124 sites show that fire, drought and insect outbreaks can be identified in the growth rings, and that natural regeneration of trees appears to be linked with the Pacific decadal oscillation (hot periods have fires and trees regenerate after the fires).

Figure 18. Salamander in HJ Andrews Watershed

Figure 19. Giant Slug in HJ Andrews Watershed

Geomorphology, land stability and erosion

Figure 20. Stem being progressively split by land slide

On the 23/6/2009 Fred Swanson and Julia Jones hosted a tour of land instability in HJ Andrews. A fine scale Digital Elevation Model derived from LIDAR was used to identify geological features such as alluvial fans at stream confluences, landslides on hillslopes and areas where streamflow had been diverted from its original course by landslides. Fred Swanson has observed that streams with alluvial fans at their confluences have much greater potential for mass movement – particularly during the peak flows that occur in Spring during snow melt. We viewed land slip monitoring in forest. The movement of 'blocks' of soil can be monitored with tensiometers. A less technical but far more interesting way of determining land movement is through regular monitoring of the width of the split of a tree growing on a slow moving landslide (Figure 20).

Figure 21. Fred Swanson and Julia Jones with grad students on the geomorpholgy field day

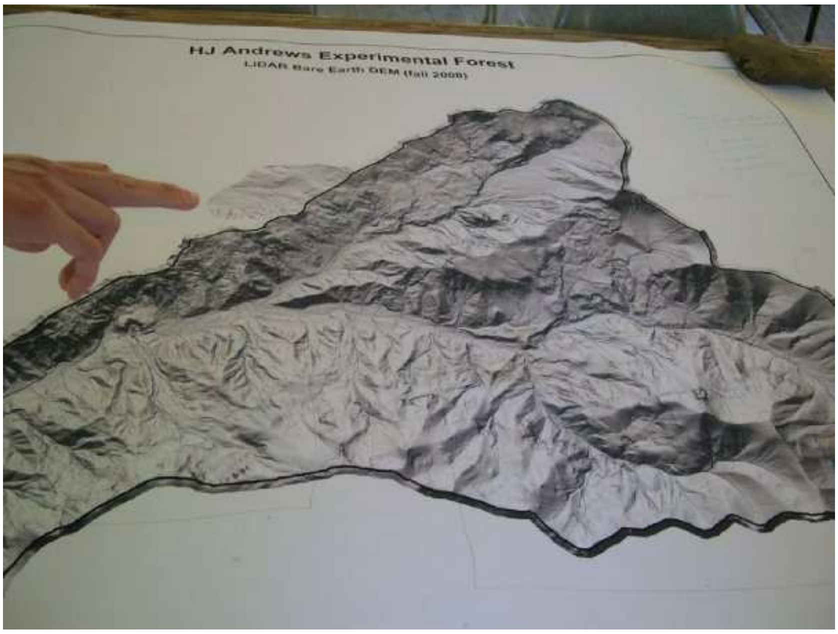

Figure 22. LiDAR Digital Elevation model used to help in identifying the locations of land slips

Hydrology field day

Each of the gauged streams in HJ Andrews has a weir and a shelter shed for the gauging instruments. The weirs and sheds are heated in winter to prevent freezing. An additional weir plate is added to the broad crested weirs after snow melt to provide more accurate measurements of low flows over summer. I helped Greg Downing with the installation of a summer weir plate, rating measurement and inspected streamflow gauging instruments at HJ Andrews. Chart recorders rather than electronic dataloggers are still used at HJ Andrews – mainly because Chart recorders were state of the art at the time the experiments were established and they have continued to run reliably so there has been no need to replace them.

Figure 23. Example of weir and instrument shelter at HJ Andrews – summer weir is in place

Figure 24. Stream volume being measured with calibrated 44 gallon drum

Data management

HJ Andrews has a team of three data managers, a GIS officer and three technicians to collect electronic data. I met with Don Henshaw (data manager). Don manages data from HJ Andrews and ensures that the web site is up to date. HJ Andrews has a policy of making data readily available, and most electronic data can be obtained online. I was particularly interested to learn what software is used to manage streamflow data and how gaps in the data are filled. Don uses multiple linear equations to describe the relationships between flow in the different catchments – that is because the relationships vary at high and low flows. Curve fitting is conducted in SAS. Don uses FoxPRO for most data management but this is being phased out by supplier. Don recommended Microsoft Access as an inexpensive option for managing Warra hydrolgy data sets - if I were to learn Visual Basic. A web program that allows researchers to extract data at the desired time intervals from the web site is written in Pearl.

Discussion

Forestry Tasmania will purchase LiDAR coverage for much of the forest estate over the next 5 years. LiDAR will be used for inventory and planning purposes and has been found to be especially useful for identifying hazards and special values (Mannes et al., 2009). We would like to be able to locate old, new and potential landslides on LiDAR so that they can be protected. It was good to see LiDAR being used to identify geological hazards at HJ Andrews.

I found it particularly useful to see how streamflow is gauged and how data is managed and distributed. We have the advantage in Tasmania of newer data logging technology and telemetry at our sites, but the quality of maintenance and data collection procedures and the thought that has gone into the design of some of the gauging stations provides and example of how we can collect data that we have more confidence in from here on.

Wind River Experimental Forest

Wind River is the oldest Experimental Forest in the USA and celebrated its 100th anniversary on 6/6/2009. Wind River is located in Washington State and was primarily established for silvicultural research although it now encompasses a wide range of ecological and other studies.

Wind River is not noted for hydrologic research studies, but the Canopy Crane (figure 25) enables studies of tree and leaf level photosynthesis, stomatal conductance, transpiration, water transport, leaf area, ecology, and carbon flux, of old growth Douglas Fir, Hemlock and Western Fir dominated forests that are up to 200 ft tall.

Figure 25. Canopy Crane at Wind River

Coweeta Hydrologic Laboratory

Coweeta Hydrologic Laboratory was established in 1934. Coweeta is based in the eastern deciduous forest of the southern Appalachian Mountains in North Carolina. The University of Georgia and the USDA Forest Service conduct the majority of hydrologic research. Construction of 16 research weirs, the road network, trails, buildings and groundwater wells utilised labour that was readily available during the depression years before World War 2. By 1939, 25 weirs were in operation, and this was increased to 30 by 1943. Today there are 17 active, permanent stream gauging sites at Coweeta (Swank et al., 2002).

Treatments in the catchments have included removal of understorey, strip harvesting, selective harvesting, tree species conversions, forest clearing and cable logging. Studies of plant-soil-water relationships, stream chemistry, responses to insect defoliation and drought, acid precipitation, non-point source pollution and nutrient budgets have also been initiated. Ecological research and ecosystem response to disturbance have also been important areas of research, and social and economic research are becoming increasingly important (Swank et al., 2002).

For a forest hydrologist, visiting Coweeta is akin to fairy floss loving child visiting Disney Land or an Agricultural Show. I attended the Coweeta LTER Science Meeting, toured the experimental catchments with Wayne Swank and assisted with the Summer Synoptic Sampling program. Because the notes for the oral presentations at the Summer Meeting are better than any synopsis that I could put together, they are provided in Appendix 1.

Coweeta has a range of stream gauging stations on streams of different size and morphology. Some are broad crested, others are standard v-notch designs. Streamflow studies assist in understanding the hydrologic cycle but are also essential in estimating nutrient balances and in understanding ecological processes in streams. Water is sampled, weather monitored and atmosphere sampled at Coweeta. The facilities at the site include an administration block, accommodation, laboratory, workshop, and offices. One of the new initiatives is a carbon flux tower which should be installed by the end of this year. Coweeta also employs an education officer and functions as a recreation area.

Figure 26. Wayne Swank at Watershed 1, White Pine Forest

Figure 27. Wayne Swank and stand of Eastern Hemlock being defoliated by Woolly Adelgid

Synoptic Sampling Program

Figure 28. Example of Synoptic sampling location in Southern Appalachians

Each Summer and Winter ecologists, hydrologist, sociologists, and chemists work together to describe water chemistry, aquatic communities, stream morphology, and the social context of 57 stream sections in a mixture of land uses in the vicinity of the Coweeta Hydrologic Laboratory. Synoptic sampling provides a seasonal snap shot of catchment condition and the data is important in understanding the long term impacts of climate change and human activity on water resources. The synoptic sampling highlighted the value of working across disciplines, and of combining sampling with the Summer LTER meeting so that researchers attending the meeting could all assist with the sampling. The large number of helpers meant that the sampling was completed in less than 2 days.

Discussion

The Synoptic sampling is a great example of the type of approach that could be used by natural resource managers to assess the condition of streams in their management areas. I have already proposed that NRM implement something similar here in Tasmania to develop maps of sediment concentrations in streams across a range of different landscapes.

Figure 29. Local Wildlife – one of the easier to count species

Hubbard Brook

The Hubbard Brook Experimental Forest is a 3,160 hectare reserve in the White Mountain National Forest, New Hampshire, managed by the USDA Forest Service Northern Research Station. On-site research has produced some of the most extensive and longest continuous data bases on the hydrology, biology, geology and chemistry of a forest and its associated aquatic ecosystems.

There are 10 gauged watersheds at the Hubbard Brook Experimental Forest. Five have been treated experimentally. Daily streamflow, streamwater chemistry, sediment yield in the weir basin data sets are available for the catchments.

- Watershed 1 was treated with Calcium at a rate of 45 T/ha in 1999. 30,000 trees in the catchment are labelled and measured

- Watershed 2 was devegetated for 3 years from 1965-1967 (with herbicides to prevent regrowth). This resulted in streamflow increases of 26-40% per year nitrogen loss increased 50 fold.

- Watershed 4 was strip cut in three phases in 1970, 1972 and 1974. Nutrient concentration increased during and immediately after strip cutting but not as much as in Watershed 2 and more desirable species regenerated than were observed after clearfelling.

- Watershed 5 was clearfelled in 1983. Harvesting resulted in increased water temperatures by as much as 6^{o}C, increased soil moisture, an increase in streamflow of 40%, increased leaching of nutrients although rapid growth of pioneer plants helped to conserve nutrients, and no appreciable increase in erosion and sedimentation.

- Watershed 101 was commercially logged in 1970 to study hydrolgy and nutrient fluxes. Streamflow increased 365 int hefirst year and returned to precutting levels by year 6. Ion concentrations increased, but returned to precutting levels by year 3.

- Remaining watersheds operate as controls

Figure 30. Same Weir as Figure 31 from different perspective

Figure 31. Example of weir designed to accurately measure low and high flows at Hubbard Brook

Coweeta Weirs are designed to allow accurate measurement of high and low flows and easy removal of sediments from the settling ponds. They do have some unique management issues – porcupines like to eat the instrument shelters so wooden shelters have to be protected against chewing, and bear and moose in the catchments lead to the occassional nervous moment for staff.

I met Kevin McGuire, a Hydrologist undertaking research at Hubbard Brook. His background is in estimating transit times in catchments and assessing hydraulic conductivity of soils using tracer studies. Weir ratings are checked every couple of years at Hubbard Brook to detect leakage. Low flows tend to be more difficult to calculate with rating curves than high flows which tend to fit theoretical relationships better. Ratings at Hubbard Brook have been developed with volume measurements or stream velocity/cross sectional area techniques, but Kevin explained that there are alternative methods. For example, ratings can be made with a slug of dye and flourometer, or salt and EC meter (Moore, 2008). The method needs to be applied during steady flow conditions.

Jim Collins (Assistant Director of National Science Foundation) gave an inspirational and informative presentation on future funding for the National Science Foundation (NSF). Current science priorities are energy, environment, and evidence based policy making. The science budget is doubling over 5 year period and will be boosted in 2009 by the US Government stimulus package. The NSF is making a particular effort to fund multi-disciplinary research. The NSF requested that scientists submit their best ideas for research. The NSF waded through the ideas with a group of scientists and a psychologist and determine who was likely to succeed with their project and to be able to work in a multi-disciplinary team. The short listed scientists were invited to a massive brain storming session, and assessed not only for their scientific ability but for their ability to cope with working with other researchers. Whole new projects were developed that combined researchers who had never previously considered working together.

Jim Collins provided some of my favourite quotes.
On keeping research relevant and being aware of disruptive technology "You're doing great work, everyone tells you that you're great then all of a sudden you're General Motors Holden".

On encouraging new ideas "Incumbents very seldom invent the future" and "Make a future rather than defending the past".

There were a series of presentations by researchers ranging from descriptions of breeding dispersal of the Black Throated Blue Warbler (Mason Cline), Effects of climate on bird breeding (Sara Kaiser, Christopher Tonra), Abundance of invertebrates (Nick Rodenhouse, Erik Stange), Hydropedology (Scott Bailey), Carbon, fertiliser and Nitrogen balance (Sam Werner, Linda Pardo, Afshin Pourmokitarian, Gene Likens, Tim Fahey), Riparian zones (Kath Harvey, Maggie Zimmer), Discharge modelling (Bob McKane), Snow (Beverley Wemple), Archiving samples (Amy Bailey), Stream Chemistry (Kojee Tamanaga, Youngil Cho, Colin Fuss), Acid rain (Steve Kahl, Charlie Driscoll), Soil nutrition and sampling (Chris Johnson, Steven Hamburg, Carrie Rose Levine, Peter Groffman, Ankit Balaria), Tree health and plant dymanics (John Battles, David Peart, Gary Lovett, Michelle Pruyn, Pam Templer, Joel Blum, Rick Boyce, Nat Cleavitt), to Information distribution (Heidi Webb).

Discussion

Hubbard Brook is another of the iconic Hydrology Research Sites, and although biogeochemistry studies appear to be the dominant area of research interest at the moment, accurately measuring water fluxes in the catchments is critical to answering many of the questions about nutrient and carbon balance.

The presentation by Jim Collins again highlighted the need for good communication between research providers, agencies and research financiers, and the need to move out of our comfort zones and to take on new and creative challenges in research.

The use of stable isotopes in hydrologic research

I was invited to attend the "Isotopes, Hydrology and Biogeochemistry Workshop" at Oregon State University (8-9th June 2009). Stable isotopes are a useful means of understanding hydrological processes and aquatic food webs.

Stable isotopes are naturally occurring forms of common elements that have extra neutrons, and so have a slightly different atomic mass. The various isotopes of an element have slightly different chemical and physical properties because of their mass differences. For elements of low atomic numbers (eg. hydrogen (H –1, 2 or 3 neutrons), oxygen (O – 16, 17 or 18 neutrons), nitrogen (N – 14 or 15 neutrons), carbon (C – 12, 13 or 14 neutrons), and sulfur (S – 32, 33, 34 or 36 neutrons)) these mass differences are large enough for many physical, chemical and biological processes or reactions to fractionate or change the relative proportion of different isotopes of the same element in various compounds. As a result of the fractionation processes, waters and solutes often develop unique isotopic compositions that may be indicative of their source or the processes that formed them. For example, as water undergoes phase changes the isotopic compositions become fractionated.

If identifying the source of water in a stream, water samples can be taken from rain, soil solution, groundwater and the stream and the isotopic signatures compared. From this data, inferences about the source of water in the stream may be made. Or, to identify sources of particulate organic matter (POM) in streams, the isotope ratios of POM in steams can be compared with that of leaves, soil, plankton, or aquatic plants.

Presentations were given on a number of isotope studies. Before this workshop I had never given serious consideration to the use of isotopes in hydrologic research in Tasmania. However, isotope research could assist in answering some of the questions we are currently asking in Tasmania and developing a better understanding of some of the techniques would be useful. We could, for example use stable isotopes in our herbicides water monitoring improvement program to better understand water flow paths to streams in landscapes where herbicides are applied – this could assist us to identify when best to test for contaminants in streams or the importance of monitoring groundwater. We could develop a better understanding of the sources of carbon in streams at Warra by comparing isotopes in soil, foliage and algae. Isotopes could be used in the plantation water use project to help understand where the trees are sourcing the water they transpire. Some of the end mixing diagrams exhibited at the workshop represent a neat way to evaluate other types of data.

Synthesis and Discussion

1. Forest Hydrology Issues in the USA

Forest hydrology research in the USA has much in common with forest hydrology research in Australia because so many of the issues are similar. In the USA, I observed researchers studying, or managers and the community discussing:

- impacts of harvesting and thinning on water quality, yield and aquatic species
- competition for water resources, especially with downstream irrigators
- studies of streamflow generation processes
- impacts of species loss on hydrology (eg. Woolly Adelgid killing Eastern Hemlock in riparian zones)
- impacts of nutrients and pollutants on aquatic species
- impacts of wildfire on streamflow and water quality
- forecasting and management of flooding
- impacts of land management change (or forest species change) on water quality, yield and aquatic species
- fish access through stream crossings
- engaging with the community and community perceptions
- valuation of land for conservation
- climate change impacts on hydrology and ecosystems

For all the topics listed above, there are Australian studies that have been established to answer similar questions. Many of the scientists that I met in the USA have already developed connections with Australian researchers, so that there is at least some flow of information between the two countries. There is always a delay in the publication of research results in peer reviewed journals, so making and maintaining these personal links with scientists working in a similar field of study to provide information on the range of projects currently under way is a way of obtaining earlier knowledge of research programs and results.

2. Design and management of paired catchment experiments

Paired catchment experiments are a common way of quantifying impacts of treatments such as harvesting, fertiliser addition or wildfire. Catchments are usually gauged over an extended period of time. This involves the installation of weirs, shelter sheds, instruments for gauging of stage height in the stilling pond behind the weir, protocols for site management and data collection. Rating curves need to be developed that link stage height to streamflow volume.

There are numerous weir designs, methods of gauging stream height, methods for development and validation of rating curves. I viewed paired catchment experiments at all of the research forests that I visited. I also spent a day at HJ Andrews with the hydrology technicians observing weir maintenance procedures, rating curve checks and data collection methods. This was useful as the Warra LTER rating curves still require refinement and there is room for improvement in the day to day management of our research catchments. Observations of note:

- Some weirs were designed to enable accurate measurement of both high and low flows.
- Some weirs had stilling ponds designed to enable accumulated sediment to be moved with a front end loader for weighing to determine bedload.
- There are standard and non standard weir designs (standard is usually best as it enables use of standard rating curves with verification), however even with standard weir designs ratings need to be regularly checked as approach conditions can vary through time.
- Heating of weir plates and shelters to prevent freezing may be necessary in cold environments.

- Many USA paired catchment studies still use chart recorders rather than electronic data loggers. This is a function of the technology that was available at the time at which the experiments were established. The chart recorders have been very reliable.
- Consistent field checking and data collection methods are important and the retention of experienced staff for long terms facilitates this.

I have not encountered weirs in Australian paired catchment experiments that are designed to cope with high and low flows – possibly because in most of Australia the heavy flows associated with snow melt are not a problem. The weirs that I am familiar with use standard v-notch or flat weir designs, however in some instances approach velocities are probably too rapid, and more effort should be put into verification of the standard flow ratings.

Many Australian experiments are funded with short-term contracts which does create difficulty in maintaining measurement programs and retaining experienced staff over extended periods.

The techniques used for low flow rating curve development at HJ Andrews (with a calibrated 44 gallon drum) would be easy to employ and would enable FT to develop their own ratings at low flows rather than relying on contractors with flow meters.

3. Communication and community engagement

Good communication between land managers, researchers, students and the community is paramount when designing experiments, developing policy or planning operations. The Coyote Creek visit highlighted:

- that research catchments are expensive to maintain, an inconvenience to forest managers (by limiting use of area) and thus need to have a very clearly defined purpose with a demonstrable useful range of outputs
- to develop useful research programs forest managers need to be able to clearly articulate their needs, what they perceive as impediments to their business or the achievement of management objectives in the present or future, and researchers need to take the time to listen, time to understand the operational systems and policy framework that forest managers are working with, to be creative, adaptive and relevant in the development of their research programs
- that the knowledge, and enthusiasm of local community should not be underestimated – nor their powers of political persuasion

4. Data Collection, transfer, distribution and storage methods

There is a strong culture of data sharing and availability in the Experimental Forests in the USA. This is largely possible because considerable resources have been invested in the construction and maintenance of hydrologic research infrastructure, collection of data, processing and storage of data, creation of web sites that enable data to be accessed from databases at whatever intensity the researcher requires. Dedicated staff are available for data collection and site management, data management, and web design. For example, at HJ Andrews, a full time technician is employed to collect field data and to maintain weirs in the paired catchments. He is assisted by casual and other staff. Three staff are retained to manage data collected at HJ Andrews. A number of postgraduate projects have been undertaken to develop the software to process and manage hydrologic data and to extract data from the database. This data is then utilised by researchers from a range of agencies and universities.

In contrast, at the Warra LTER, until quite recently a single person has been responsible for weir maintenance, data collection, sample collection, data management and processing and data analysis. It is challenging to achieve the objectives of the project with such limited resources. In the last 6 months we have obtained resources for telemetry at the three weirs which significantly reduces the time spent in the field and we have engaged Hydro Tasmania to manage data. More effort still needs to be put into data storage and transfer to researchers.

5. The importance of sample storage

In 1990, an archive facility was built at the Hubbard Brook Experimental Forest to store samples permanently so that they will be available for future research. The archive building houses approximately 40,000 samples of soil, water, plant tissue, and other materials. Samples are preserved, barcoded, and catalogued with accompanying metadata in a database.

While there are many analyses that would not be recommended with old samples, there are also many analytes that are stable through time that can be usefully studied in older samples (eg. heavy metals, isotopes). Stored samples at Hubbard Brook have been reanalysed resulting in publication of 18 additional papers on soil or water chemistry.

I think it is important for Australian researchers and land managers to consider if sample storage may be useful. There may be questions in the future that could be answered by re analyses of archived samples.

6. Synoptic sampling at Coweeta

At Coweeta I participated in the Summer Synoptic sampling program – ecologists, hydrologist, sociologists, and chemists work together to describe water chemistry, aquatic communities, stream morphology, and the social context of 57 stream sections in a mixture of land uses in the vicinity of the Coweeta Hydrologic Laboratory. Synoptic sampling provides a seasonal snap shot of catchment condition (it is also undertaken in winter) and the data is important in understanding the long term impacts of climate change and human activity on water resources. The synoptic sampling highlighted the value of working across disciplines, and of combining sampling with the Summer LTER meeting which mobilised a large number of participants in the program so that it was completed in less than 2 days. This type of sampling would answer some of the questions being asked by Natural Resource Managers, Government Departments and policy makers in Australia, and could be used to validate existing models that predict water quality parameters or sediment loads in Australian Landscapes (eg. WaterCAST, NRM North, Tasmania).

7. Long term hydrological monitoring

Paired catchment experiments require long-term monitoring – usually for many decades. This type of monitoring requires the lead agency to make a long-term commitment to the study. The best results are usually achieved where paired catchment studies are run by committed agencies that continuously employ the same experienced staff to run the project and where these staff have a sense of ownership of the project (eg. Wayne Swank at Coweeta).

The USA is similar to Australia in that much funding is short term, but it is fortunate that USDA and LTER programs appear to provide stable funding for some research and monitoring. Researchers in USA as is the case in Australia continuously seek sources of funding for their research.

It was interesting to note in the Coweeta LTER Winter Meeting Minutes that resignation of a senior staff member had revealed that not all observations had been recorded during his tenure resulting in a significant loss of knowledge with his departure. Our experiences in the Warra LTER are similar – the knowledge frequently leaves with the staff. This means that clear documentation of all measurements, observations and activities, and protocols for data collection, handling and storage are essential for future users of the data to have confidence in data quality and completeness.

8. Aquatic species management and impacts

As a forester working as a hydrologist, some of the research opened my eyes to a whole new way of thinking. I had never thought of aquatic creatures as a store of nutrients that could just swim, hop or walk out of a catchment taking their nutrients with them. Nor of the significance of the death of a small number of large animals such as moose or a large number of small animals such as salmon as a significant nutrient input to a catchment.

In Australia we are aware that fish still need to be able to pass through stream structures, but in the USA not only do they have to ensure fish passage to allow breeding, but have to manage Beaver dams so that the dams do not engulf infrastructure or become so large that when they break substantial downstream damage occurs.

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Appendix 1. Abstracts of Oral Presentations Coweeta LTER 2009 Summer Meeting

Coweeta LTER 2009 Summer Meeting – List of Presenters

ORAL PRESENTATIONS – Monday 29 June

Estimation of microbial and animal mineralization across a gradient of nutrient availability

Beth M. Cheever, Jack R. Webster, and Erika B. Kratzer
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The importance of nutrient regeneration by animals to meeting stream inorganic nutrient uptake depends on the relative importance of microbial mineralization and exogenous nutrient supply. We determined the relative importance of animal excretion and microbial regeneration to stream NH_4^+ uptake across a gradient of ambient N availability. Disks cut from chestnut oak leaves collected from each stream were incubated in filtered stream water, spiked to increase NH_4-N concentrations, and sampled periodically over four hours to determine microbial uptake rates. Microbial mineralization rates were calculated using these uptake rates and steady state nutrient concentrations. Excretion rates of dominant macroinvertebrate taxa were measured *in situ*. We used animal and leaf biomass estimates to scale these rates to reach-level fluxes. These fluxes were compared to whole stream N uptake as determined by step-wise solute injections. Microbial mineralization rate was similar across sites. However, both microbial mineralization and animal excretion as proportions of uptake varied considerably among streams, ranging from <1-77% and 30-145% respectively.

Are stream consumer dynamics different on deciduous (*Acer rubrum*) versus evergreen (*Rhododendron maximum*) leaf packs?

John R. Frisch and Catherine M. Pringle
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In the southern Appalachians, macroinvertebrates and salamander larvae are consumers critical to stream food webs, and use deciduous and evergreen leaves as habitat and/or food. A diversity of deciduous trees contribute large amounts of labile litter in autumn, while evergreens (primarily *Rhododendron maximum*) provide smaller inputs of recalcitrant leaves year-round. In- stream, deciduous litter breaks down within months, while Rhododendron persists 2-3 years. It is important to understand the role of Rhododendron given the uncertainty surrounding predicted changes in its relative abundance: while it may increase in abundance following hemlock extirpation due to ongoing Woolly Adelgid infestations, it could decline if pathogens invade and/or droughts arise. Here we examine consumer biomass, abundance, and presence/absence on single species leaf packs of deciduous *Acer rubrum* and evergreen *Rhododendron maximum*, incubated during autumn in streams draining Coweeta Hydrological Laboratory in North Carolina. Even though our leaf packs were embedded in a matrix of freshly-fallen high-quality deciduous leaves, six of twenty-two consumer taxa occurred significantly ($p<0.1$) more often on Rhododendron; five of these six taxa were predators or long-lived taxa. One stonefly (*Beloneuria*) occurred significantly more frequently on Acer. Our results indicate that Rhododendron is an important autumn litter resource for some insects (*Anchytarsus*, *Pseudolimnophila*, *Lanthus*, and *Ceratopsyche* spp.), crayfish (*Cambarus* spp.), and salamanders. Consumers found more frequently on Rhododendron have similar life history and behavioral traits (long-lived taxa and sit-and-wait predators) and are likely taking advantage of the relatively stable microhabitat provided by Rhododendron tubes within the stream environment.

How do detritus-based pathways respond to nutrient enrichment in streams?: what we've learned and what we hope to find out

Amy D. Rosemond[1], Keller Suberkropp[2], J.Bruce Wallace[1], Vladislav Gulis[3], Wyatt Cross[4], J.M. Davis[1], Jonathan Benstead[2], and John Maerz[5]
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[5] Warnell School of Forestry and Natural Resources, University of Georgia

Previous studies at the Coweeta LTER have revealed striking effects of nutrient enrichment on detritus-based, headwater streams from the microbial to ecosystem level. Changes in ecosystem rates such as carbon processing and export were apparently caused by 1) increased microbial production that 2) drove changes in stoichiometry of organic matter that resulted in 3) increased carbon and nutrient flows to consumers and 4) greatly accelerated export of particulate organic matter and reduced carbon storage. These results are contributing to an expanded view of the effects of nutrients in aquatic systems that include both autotrophic and heterotrophic pathways and can aid predictions of potential alterations in the rates of storage and processing of carbon in rivers and streams faced with chronic nutrient enrichment. Our previous research was based on a 5 year continuous enrichment of a single stream at Coweeta at roughly Redfield ratios of nitrogen and phosphorus (N:P 15:1) compared to a reference stream. Our recently funded proposed research will build on our previous work to fill gaps in current understanding of the *concentrations* and *ratios* of N and P that stimulate heterotrophic response in aquatic systems.

The upper Little Tennessee Watershed Biomonitoring Program: nineteen years and counting

Bill McLarney[1] and John Chamblee[2]
[1] Little Tennessee Watershed Association
[2] Coweeta LTER Information Manager, University of Georgia

Nearly nineteen years of Index of Biotic Integrity (IBI) fish data have been collected from 474 surveys across 156 sites in the upper Little Tennessee watershed. Dr. Bill McLarney and the Little Tennessee Watershed Association has partnered with Coweeta LTER to curate and host this valuable long-term dataset. We will discuss the background of this project, talk about how the data are structured, and hopefully get folks excited about the research possibilities that exist with such a rich dataset.

Protecting a much-loved park: research, research needs, inventories, and monitoring in Great Smoky Mountains National Park, NC/TN

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[2] Great Smoky Mountains National Park, NPS, Tennessee

Over 210,000 hectares straddling the North Carolina-Tennessee state line were designated as Great Smoky Mountains National Park (GRSM) 75 years ago this year. As a unit of the National Park Service (NPS), the Smokies is bound by the mission to "...to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations [National Park Service Organic Act of 1916 (16 USC 1)]." GRSM has long attracted scientific study and GRSM staff has sought to make us of this research to guide its management. In 1992, GRSM was selected as one of the first four

"pilot parks" for the new Inventory and Monitoring program being tested by the NPS. The GRSM monitoring program is currently undergoing review. In 1997, GRSM launched the first ever inventory of all plant, animal, and fungal species within a conservation area in North America: the All Taxa Biodiversity Inventory. Georeferenced specimens are collected by taxonomic experts themselves or by trained volunteers and distributed to participating taxonomists, with records entered into an access database, now available online. Nearly 17,000 species have been documented. A soils map documenting 20 new soil types—and updates of vegetation and geology maps have recently been completed to assist with modeling of species distributions. GIS models of atmospheric deposition, surface temperature, and disturbance history have also recently been developed. In 2001, GRSM was selected to host one of the first 5 Research Learning Centers in the NPS: the Appalachian Highlands Science Learning Center. This program to facilitate research in the park and to improve the retention of research findings, seeks to develop new research partnerships for GRSM. The National Ecological Observatory Network (NEON) has selected a site on the Tennessee side of GRSM for one of its relocatable observatories to study the impacts of climate change, land-use change, and invasive species on ecology, expected to be launched in 2011.

Warra LTER Site, Australia

Sandra Roberts
Forest Research and Development, Forestry Tasmania

The Warra LTER was established in 1990 to enable ecological and silvicultural research in native, eucalyptus-dominated forests in southern Tasmania. Results of research will assist in the management of forests for a range of values including wood produciton and nature conservation. A selection of the research projects will be described including silvicultural system trials, fire impact studies and hydrology monitoring.

Coweeta LTER Schoolyard Program

Jennifer E. Love
Coweeta LTER Schoolyard Coordinator, University of Georgia

The Coweeta LTER Schoolyard program continues to work with local middle schools in North Carolina and Georgia. The program is taking a new direction in order to reach more students through citizen science and science boxes. The citizen science initiatives, such as stream salamander monitoring, take place on school grounds to allow more students to participate in the project. The science boxes consist of equipment such as metric tapes and kick nets, as well as lesson plans that correlate to science curricula in each state. It is our hope that these new initiatives will not only help teachers meet their curriculum objectives, but also engage students in real and relevant science.

The value of conservation restrictions

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The objective of this paper is to examine the price effects of conservation land use restrictions. Conservation restrictions occur when the owner of land grants title to a grantee for the purposes of conservation, or when the owner grants some of the rights to use the land, but retains the right of disposition. With the latter method the grantee is given an easement that "runs with the land," meaning future owners of the property are similarly bound by the terms of the easement.

The analysis reveals how the value of donated parcels compares to similar properties before the donation. It also reveals the extent to which property burdened with conservation easements sells for less than a comparable property without such restrictions. Finally the analysis measures the benefits or costs that accrue to nearby property following donation activity. The results suggest that prior to a donation, land near properties on which donations are ultimately placed appears to be associated with lower value. The results also suggest that properties burdened with conservation restrictions sell for a significant discount relative to comparable property. Finally, proximity to parcels on which conservation restrictions have been placed appears to be associated with higher value.

Thinking about the land. Understanding perceptions of exurban development in the Swannanoa Valley through a PhotoVoice project (Buncombe County, North Carolina)

Anne L. Sourdril and John F. Chamblee
Department of Anthropology, University of Georgia

Social scientists, policymakers, and the public need to understand how inhabitants of exurbanized areas think about and perceive their land. This study used a combination of the PhotoVoice and participatory GIS method to capture these perceptions. Our results show that while exurban development is commonly discussed as a phenomenon related to "sprawl", people do no actually perceive development as systemic, but instead focus on development patches that are located in restricted locations. As a consequence, they focus on the protection of nearby land – creating associations and relationships with their neighbors – and thereby providing at the same time a revitalization of their community and territory. While these approaches do support increased social networking and some local environmental protection, they do not necessarily foster the creation of policies with broader impacts.

Topography-mediated controls on local vegetation phenology estimated from MODIS vegetation index

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Near real-time remote sensing imagery are useful tools to integrate spatial phenological signals across different scales. In this paper, we used the 8-year moderate-resolution imaging spectro-radiometer (MODIS) vegetation indices (2001 ~ 2008) to find the topography-mediated vegetation phenology at the Coweeta LTER site. A simple post-processing analysis using multi-year trajectories provides a very efficient way to filter out false data points. Four local phenological variables (mid-days of leaf-on/off, lengths of leaf-on/off) were estimated by fitting time-series of transformed vegetation indices with a difference logistic function, related with local topographical variables by the multiple regression analysis. Elevation has most explanatory power for all phenological variables. With elevation, the mid-day of leaf-on shows a strong linear relationship, while other three variables show quadratic responses. Radiation proxies (transformed aspect or potential relative radiation) also have some explanatory power except for the mid-day of leaf-on variable. Even though not so much effect of hillslope positions on vegetation phenology are shown at this coarse resolution (about 250 m), interannual variations of vegetation

phenology between very wet and dry years shows that more extended periods of leaf-on/off were found without shifting mid-days of leaf-on/off. These topography-mediated controls on local vegetation phenology are closely related to micro-climatic variations, vegetation community types, and hydrological positions at this study site.

Climate change: ecologists think global, climate acts local

Robert J. Warren II and Mark A. Bradford
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An enormous discrepancy exists between climate trends at global and regional scales but ecological researchers commonly assume global and annual means in explaining local or regional ecological patterns. We illustrate the problem with such assumptions with a case study of climate trends (1931-2004) in the southern Appalachian region. We tested whether regional warm and cool season temperature and precipitation trends reflected that of the global mean or the North Atlantic Oscillation (NAO) index, and whether global temperature trends or NAO better predicted stream salamander abundance in the region. Our results suggest that more than half of the climate change research in the ecological literature assumes annual global means rather than regional climate when explaining ecological trends. These results are disconcerting in light of our findings that global trends poorly correspond with southern Appalachian temperatures and precipitation as well as salamander abundance.

Modeling climate change effects on the function of southern Appalachian stream salamander communities

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Changes in biodiversity are predicted to have a major impact on ecosystem processes. A fundamental challenge for ecologists is to determine the influence of species on ecosystem processes prior to declines or losses, and to determine whether there are species that may compensate for the loss of other species. The southern Appalachian Mountains are a global hotspot for stream plethodontids. Plethodontids are the numerically dominant vertebrate predators of high-elevation first order streams, and as such are hypothesized to be influential in the capture and retention of nutrients and the flow of energy to higher trophic levels. Our objectives were to determine the potential consequences of a reduction of stream salamander diversity to nutrient capture and retention within first and second order streams at the Coweeta Hydrological Laboratory. To meet this objective, we used ecological stoichiometry to estimate the amount of nutrients captured and exported by a stream salamander community, generated predictive models of species loss under climate change scenarios, and used field removal experiments to determine whether predicted species losses alter nutrient capture and retention or whether there is compensation by other salamander species or stream fauna. We found stream plethodontids are significant nutrient reservoirs when compared to other stream taxa and are influential to stream nutrient cycling; however, models project a decline in suitable habitat associated with climate change scenarios for many species within the Coweeta basin. Further, our results suggest that while subordinate plethodontid species respond positively to the loss of the dominant species, there is still a net loss of salamander biomass produced within streams. These results suggest that the potential loss of some salamander species from the region that includes Coweeta could have significant implications for stream function including the capture, retention and ultimately export of nutrients.

Convergence of microbial community function in common environments is associated with loss of function in alternate environments

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Consisting of populations with short generation times, it is commonly assumed that there is a high degree of functional redundancy within soil communities with respect to broad-physiological processes (e.g. organic carbon decomposition). However, microbial communities display biogeographic patterns, even at fine scales. New work shows that these biogeographic patterns extend to microbial community function, with functioning influenced by differences in resource histories. We examined whether a common resource history might cause functionally dissimilar communities to converge functionally. Next, we tested whether functional convergence (partial or complete) is associated with a reduction in function in alternate environments (a functional 'trade-off'). We used a 6 × 2 (soil community inoculum × litter environment) full-factorial design under controlled, laboratory conditions. Our results suggest that distinct microbial communities can converge functionally when exposed to a common environment, and that convergence is associated with loss of function in alternate environments.

Modeling tree demography and interacting disturbances using long-term seedling experiments

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Community composition of eastern deciduous forests will shift as temperature and precipitation regimes change in response to anthropogenic climate change. Early and late season frosts can cause premature leaf abscission and drought can lead to carbon starvation or catastrophic cavitation of the xylem. Seedling responses are further complicated by interactions with other factors, such as hurricane disturbance, deer herbivory, and rising atmospheric CO_2. High-dimensional trade-offs result in complex responses in community composition, making prediction difficult with traditional statistical and experimental approaches. Using data from a series of long-term seedling experiments in the Southern Appalachian Mountains (Coweeta LTER) and the North Carolina Piedmont (Duke Forest), we propose to examine the influences of climatic variability and experimental forest manipulations on seedling growth and survival using a hierarchical Bayesian approach. We modified an existing forest demographic model to analyze tree seedling demography and the influences of environmental covariates, annual variation in frost and drought events, experimental treatments, and random individual temporal effects (RITEs). Examinations of these interacting effects will help inform predictions regarding future forest dynamics as climate changes and forests are altered by human and natural disturbance.

Hydrometeorological network deployment, numerical simulation and remote sensing monitoring integration to investigate orographic effects over the Great Smoky Mountains Area

Ana P. Barros, Olivier P. Prat, Xiaoming Sun, and ***Julien Brun***
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Rainfall varies greatly across the mountains of North Carolina causing widespread flooding and landslides. For instance rainfall accumulations of up to 18.5" and 17" were measured over a 24 hour period during the passage of Hurricanes Frances (the highest in the continental US) and Ivan respectively in 2004 (by then tropical depressions) in Western North Carolina. The rainfall amounts recorded correspond to orographic enhancement factors on the order of 300% around Ashville, NC. In that sense, the region offers a unique setting to study both warm and cold season orographic precipitation regimes: a) a cold season orographic precipitation regime associated with post-frontal northwest flows that lead to a west (high)-east (low) gradient of snowfall; and b) a warm season orographic precipitation regime associated with the passage of intense storm systems including southerly and easterly tropical depressions. How the terrain modifies the microphysical and dynamical processes that govern precipitation as weather systems approach and pass over the mountains is not yet understood and the effect of the terrain on localized convective storms is also unknown.

In order to understand those mechanisms, a high-spatial resolution rain gauge network has been installed in the Southern Appalachians since summer 2007. This dense rain gauge network is specifically designed to capture orographic precipitation gradients in surrounding ridges. Since two additional field campaigns have been conducted in the Great Smoky Mountains National Park (GSMNP) in July-August 2008 and in October-November 2008 involving the deployment of vertically pointing radars in order to investigate the mechanisms and microphysical properties of summer/fall and mountain/valley precipitation. The objective was to collect observations to document summer/fall interactions between landform and storm systems in western North Carolina. Besides these field experiments, efforts have been conducted to enhance numerical simulations of tropical cyclone (TC) precipitation using the Weather Research and Forecasting numerical model (WRF-ARW v3.0, NCAR) at 1 km resolution. Here we present results for the simulation of the hurricane Ivan over the Appalachians. Preliminary intercomparison with observations suggests the model captures well the spatial and temporal variability with rainfall, especially with regard to the triggering of the Wayah and Peeks Creek debris flows. Finally, to investigate the impacts and the strategies of recovery of the environment in the aftermath of such intense meteorological events, remote sensing data have been processed to systematically monitor vegetation disturbances along the track of major TCs hitting the southeast US.