New Mexico EPSCoR Innovative Working Group Summary Report

Title: A stoichiometry of the Rio Grande: Using novel observational techniques to understand the sources, patterns, and dominant drivers of solutes and greenhouse gas emissions

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The IWG team. From left to right and front to back: Sarah Miller, Jesus Gomez-Velez, Brian Bergamaschi, Ricardo Gonzalez-Pinzon, Dave Van Horn, Justin Reale, Cameron Herrington, John Wilson, Cliff Dahm, and Brent Newman (some of the IWG members could not be present during the picture).

IWG Summary

Rivers are the earth's arteries — they convey water, solutes, energy, and living organisms from the landscape, subsurface, and atmosphere to the oceans. Understanding and predicting spatial and temporal variations in water quality and greenhouse gas emissions along this complex circulatory system is critical for sustainability and management under present and future socio-economic and climatic conditions. In this regard, water-limited environments such as the Rio Grande basin are particularly challenging targets, given their complex interactions among hydrologic forcing, flow regulation, and geology, as well as the uncertainties in water and solute inputs. Over the last decade, the advent of new technologies dramatically increased our ability to observe and quantify critical riverine processes at multiple spatial and temporal scales, opening the door for fundamental advancements linking observations and theory. This Innovative Working Group (IWG) will guide discussion to draft a synthesis article on our current understanding of the Rio Grande's water quality and facilitate a proposal development that leverages current observational infrastructure, acquired under the EPSCoR project, and proposes additional state-of-the-art measuring techniques for high-frequency local and synoptic observations. Adequate quantification of the Rio Grande's water and solute sources; greenhouse gas emissions; natural and anthropogenic controls in hydrology, geomorphology and geology; and drivers of physical and biogeochemical evolution will translate into more effective management practices for this complex system.

IWG rationale and expected outcomes

Previous observational efforts along the main stem of the Rio Grande basin highlight the relative importance of irrigation, evapotranspiration, wastewater inputs, and shallow and regional groundwater flow on water quality. However, these observations are limited to subsections of the river and use coarse temporal and spatial resolutions that limit our ability to fully capture the complex and highly dynamic nature of these water quality patterns. Recent advances in observational techniques can fill this gap, allowing us to better quantify the solute and gas budgets of the Rio Grande and link observations and theory to improve our predictive capabilities.

The IWG addressed the following questions:

1) What are the fundamental measurements and spatial and temporal scales needed to characterize the dynamics and variability of the Rio Grande's water quality and greenhouse gas emissions?

2) At the local scale, what kind of continuous, high-resolution instruments are needed and where are their optimal sampling locations? Moreover, can the current infrastructure provide or complement our observational requirements?

3) At the synoptic scale, what is the optimal synoptic sampling scheme that adequately incorporates local, high-resolution observations and characterizes the contributions from irrigation, evapotranspiration, wastewater inputs, and shallow and regional groundwater flow? Moreover, when is the ideal time for these synoptic surveys?

4) How can we translate these observations into better theory and predictive tools?

The anticipated outcomes of the IWG were

1) Drafting of a synthesis article on our current understanding of the Rio Grande's water quality that we will seek to publish in an appropriate general science venue (e.g., EOS)

2) Identification of critical questions and instrumentation needs within our basin to address the key questions being asked

3) Development of ideas and approaches that will lead to a competitive research proposal

4) Identification of potential grant programs for interdisciplinary research proposals from our IWG

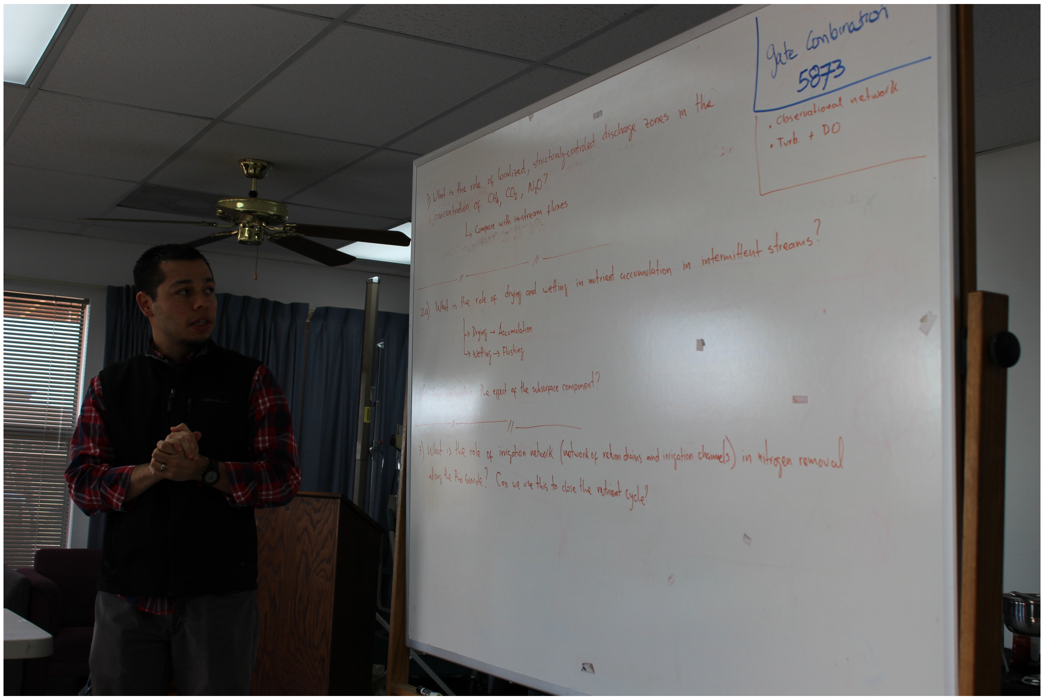
IWG Structure and Approach

This IWG brought together a multidisciplinary group of scientists with expertise in physical hydrology, ecology, geology, geochemistry, and biogeochemistry to encourage collaboration and discussion of science questions regarding the key processes that control water quality in the Rio Grande and the observational needs required to characterize them. The lead investigators ensured that scientists from New Mexico's universities (New Mexico Tech (NMT), University of New Mexico (UNM), and New Mexico State University (NMSU)) and state and federal research institutions (New Mexico Bureau of Geology & Mineral Resources (NMBGMR), Los Alamos National Lab (LANL), and the U.S. Geological Survey (USGS)) were invited and were in attendance. There were four attendees from NMT (John Wilson, Dan Cadol, Sarah Miller, and Jesus Gomez-Velez), five attendees from UNM (Cliff Dahm, Ricardo Gonzalez-Pinzon, Dave Van Horn, Cameron Herrington, and Justin Reale), one attendee from NMBGMR (Michael Timmons), one attendee from LANL (Brent Newman), and one attendee from USGS (Brian Bergamaschi). Lamentably, scientists from NMSU couldn't attend. We had a last minute cancellation from Sam Fernald, and Lambis Papelis did not respond to our invitation. The requirement for multi-institution representation and multidisciplinary collaboration was met, but NMSU participation would have been useful.

The goals of the IWG were achieved through a combination of individual presentations, break-out sessions, and open discussions. Individual presentations were requested from each participant beforehand in order to learn more about the individual's research as it relates to the science questions and to determine how their research addresses the science questions of the IWG. Individual presentations took place during the morning of Day 1 and were followed by a group discussion and brainstorming of the previous research and available datasets related to the IWG science questions. Our review of previous contributions focused on high-frequency local observations, synoptic observations, and data mining, assimilation, and modeling. Day 1 concluded with a discussion of the synthesis paper, emphasizing the main topics and questions to be addressed. This manuscript will serve as a guide for related research proposals.

Our group discussion highlighted the importance of a synthesis paper that focuses on three major controls on water quality and greenhouse gas emissions along the Rio Grande basin: (1) the anthropogenic controls driven by the complex network of irrigation canals, storage, and point sources along the river corridor, (2) the intermittent nature of the Rio Grande network, and (3) the strong geologic control of the Rio Grande Rift. The break-out sessions were held to take advantage of the diverse set of skills present within the group in order to encourage the development, testing, and exchange of interdisciplinary ideas tackling these controls. Each group, lead by two participants, focused on one of the major controls. Group 1 discussed Control 1 and was lead by Dave Van Horn and Ricardo Gonzalez-Pinzon. Group 2 discussed Control 2 and was led by Dan Cadol and Cliff Dahm. Group 3 discussed Control 3 and was led by Jesus Gomez-Velez and Fred Phillips (Fred Phillips did not attend the meeting, but already agreed to work on the manuscript and related research proposals). The group leaders will serve as a liaison with Jesus Gomez-Velez, who is in charge of coordinating the writing effort and consolidating the individual group contributions into a single and consistent manuscript. Break-out sessions were conducted during the afternoon of Day 2 and a representative from each group provided a detailed list of their findings during the evening.

On Day 3, we chose an open discussion format to address tentative Requests for Proposals (RFPs) and future research. The group agreed that a better approach to this broad and complex topic is to write a synthesis paper and then reconvene to elaborate on research proposals. Evening social events were held to encourage communication and collaboration across disciplines. The IWG group broke up after breakfast on Day 3. A copy of the final agenda is attached at the end of this report.



Brainstorming and discussion of previous research and available datasets. Jesus Gomez-Velez is taking notes on the board

Hiking in the Sevilleta National Wildlife Refuge after a long day of work. From left to right: Dan Cadol, Brent Newman, Cliff Dahm, and Brian Bergamaschi

IWG Outcomes

The Rio Grande Basin is an ideal system to understand flow, transport, and transformations in semiarid environments. Interactions during the IWG allowed participants to exchange ideas and initiate collaborations that will result in manuscripts and research proposals addressing basic and applied science of interest to New Mexico and the Nation. The state has the workforce to take on this challenge, and the IWG was the ideal setting to identify local researchers with interest in semiarid hydrology and nutrient cycling. There are two main deliverables in progress:

1. A synthesis paper: the IWG group drafted an outline for the synthesis paper (see below), highlighting the main ideas and key publications and data sources to use. The manuscript was divided into three main subsections, which involve several of the attendees but are each led by two researchers. These leaders will coordinate with other members of the group and write each section. Then, these sections will be consolidated into a single document and revised for consistency by Jesus Gomez-Velez. The *Ecohydrology* journal was selected as the preferred target for this manuscript; however, other alternatives were explored during the meeting. Each group will have a **rough draft by May 30, 2015**, and the introduction will be based on this initial draft and sent back to the group by **June 15, 2015**. A complete draft of the manuscript will be ready by **August 7, 2015**, and submitted to the journal in September. After iterating the first draft in May, a teleconference meeting will be scheduled for June to discuss proposal topics and hypotheses and target RFPs.

2. Formal establishment of the *hydrology and biogeochemistry of dryland river systems* research group: for decades New Mexico has had a strong and productive group of scientist focusing on water quantity and quality issues. To maintain this productivity during the current generational shift and encourage inter-institutional collaboration, the early-career faculty that attended the IWG (Dan Cadol, Ricardo Gonzalez-Pinzon, Dave Van Horn, and Jesus Gomez-Velez) will lead the creation of a formal research group that focuses on *hydrology and biogeochemistry of dryland river systems*. These researchers will draft initial foci for the group, invite other scientists within NM institutions, and create a web site that advertises the group and serves as an outlet for its science and initiatives. While the group will involve senior scientists, the leadership and main efforts will come from early-career scientists.

Synthesis Paper Outline

Synthesis paper

Dryland Rivers: A review of natural and anthropogenic controls on water quality and greenhouse gas emissions

General idea: We will focus on three of the key mechanisms controlling water quality along the Rio Grande basin: (1) the anthropogenic controls driven by the complex network of irrigation canals, storage, and point sources along the river corridor, (2) the intermittent nature of much of the Rio Grande river network, and (3) the strong geologic control of the Rio Grande Rift. Because these features are ubiquitous in semi-arid watersheds throughout the southwestern part of the United States (and in many other semi-arid systems worldwide), using the Rio Grande as an example allows us to make a general case for the need for mechanistic understanding of these controls and the design of adequate observational networks.

1. Introduction (lead by J. Gomez-Velez)

The introduction should highlight the following points:

- Dryland rivers as important ecological and hydrologic systems with a global perspective. Include basic information about the percentage of global population living in this areas and their ecological significance. Some key references include: [*Acuña et al.*, 2014; *Datry et al.*, 2014].
- With climate change drylands will become more abundant ([*Kingsford*, 2006] has good numbers to illustrate this point).
- Link water and nutrients as limiting factors in these systems
- Spatial and temporal variability of drivers (precipitation and temperature), state variables (soil moisture, ground water table, vegetation, geomorphology), and fluxes (discharge, evapotranspiration, etc.)
- Geologic setting and its importance in the context of flow and transport along the river system.
- Highlight the issue that dryland rivers are affected by hydraulic structures (dams, parallel irrigation/drainage channels).
- Conceptual model - pictorial representation of:
    - Intermittent channels
    - Geologic structures
    - Human impacts (urban storage/withdraw) (plus other major drivers/stressors?)
    - Add small figures depicting expected impacts to water quality/gas emission?

Structural and tectonic controls (lead by J. Gomez-Velez and F. Phillips)	**Intermittency controls** (lead by C. Dahm and D. Cadol)	**Anthropogenic controls** (lead by D. Van Horn and R. Gonzalez-Pinzon)
2. Overarching hypotheses		
Localized discharge of solutes and greenhouse gases (CO_2 and maybe CH_4) from lithogenic sources (abiogenic deep mantle-derived) in tectonically-affected rivers plays a major role in the river's water quality and greenhouse gas emissions. In addition, the effect of this lithogenic control is comparable (and in some instances larger) than the effect of shallow groundwater or in-channel controls	Intermittent channels play a major role in the delivery of sediment, solutes, nutrients, gases, and water to the Rio Grande	Human interactions and impacts dominate the hydrology and sources and sinks of solutes in dryland rivers
General Ideas		
Tie this control to dryland rivers. This type of geologic control is ubiquitous throughout the southwestern US. Then		

use the lithogenic inputs to the MRG as an example of a specific structural control		
3. Key points that highlight the importance in dryland systems in general		
➢ Reference the work of [*Butman and Raymond*, 2011], emphasizing that their work ignores lithogenic sources, which can be especially important in tectonically-active zones in the continental United States (CONUS), in particular southwest and northwest US (see figure in [*Crossey et al.*, 2015]) ➢ These contributions are stable in time, while other sources can be highly affected by climate change and land use and land change (LULC) ➢ These sources can be important contributors of minor and major ions ➢ Every spring is not the same. Some may be fed by long groundwater flow paths. 3He/4He can help us distinguish among these end-members.	Roles of intermittent streams: ➢ Source of sediment • Data- Rio Puerco sediment load; imbed photos of Puerco in flood ➢ produce oxygen demand (post burn & urban oxygen sags) • Data- Las Conchas & urban oxygen sags ➢ Pulses of solutes, nutrients, greenhouse gas (pulsed dryland systems) • Data- Sondes at alameda downstream of Abq • Data- Los Alamos ISCOs possibly? • Data- alkalinity pulses in groundwater ➢ Sustained source of GW (& solutes?) • Data- Brent's piezo & chemical data from alluvial aquifers • USGS sediment data	➢ In water scarce regions an average water molecule is utilized many times before exiting the system (i.e., recycling and reuse -- look for supporting data). ➢ Due to the highly engineered system, adding to the complexity of these rivers, stakeholders/agencies lose track of water management responsibilities. Who regulates what? and how do they track water rights/compacts? (talk with Bob Berrens at UNM and others). ➢ In dryland rivers humans strongly influence river hydrology through water storage and surface and groundwater withdrawals and returns for human consumption and irrigation. Associated with these hydrologic alterations are modified solute fluxes ➢ Point sources dominate nutrient inputs (e.g., limited application of fertilizers to the landscape) ➢ Human engineered hot-spots and hot-moments of biogeochemical processing alter/reduce nutrient exports from dryland catchments
4. Specifics of the Rio Grande River basin		
	➢ The RG itself is intermittent ➢ Processes (Spatiotemporal dynamics) • Episodic rainfall • Wetting/drying; • Limited connectivity (in space and time); • Groundwater dominant between flood events; • Limited riparian vegetation • Snowmelt	
5. Analyses and results		
➢ Concentrations above and below the hot-spots (gases and trace elements) ➢ Derive the actual gas fluxes to the atmosphere from the water concentrations (exchange coefficients		

depend on channel flow and atmospheric conditions) ➢ Compare with other fluxes to the atmosphere (e.g., estimates by [*Butman and Raymond*, 2011]) ➢ Estimate flux of water discharging from springs		
6. Preliminary data and additional observations		
➢ Compile data for Cl, Br, Sr, and other major and minor ions and stable isotopes along the sections of the river with lithogenic discharge. Data provided by Fred Phillips) ➢ Compile data on Helium, pCO2 (methane, if available or from observations). Compare with similar systems elsewhere (e.g., Yellowstone). Data provided by Laura Crossey ➢ Cross-sectional models of the area (model provided by Mark Person) ➢ Compare with Dave Buttman's modeled values of pCO2 in this reach (Brian Bergamaschi can contact him if needed) ➢ Collection of pCO2 and methane (Brian can measure some in his lab, there may be a possibility of equipment loan or someone from his group participating) ➢ Use some ion concentrations or ratios that are unique or characterize these brines and compare with NAWQA observations at a continental scale. We need to do some homework to decide the ideal solutes for this question ➢ Use the isotopes in methane to make sure that it is not biological methane	➢ Intermittent gages in RG basin-Salado, Puerco, Galisteo, Los Alamos gaging network, North diversion channel in ABQ ➢ Estimate basin area drained by intermittent channels ➢ IRBAS data sets ➢ Perched vs. flat gradient streams? ➢ Flood size affects groundwater in a different way than surface flow	Hydrology: ➢ Middle Rio Grande [*Dahm et al.*, 2002; *Oelsner et al.*, 2007] ➢ Nile (find a citation?), Murray-Darling (citation?) [See examples from [*Kingsford*, 2006]] Point source solute inputs: ➢ Middle Rio Grande [Passell et al., 2004, 2005; Oelsner et al., 2007] and Van Horn et al. 2015: It is estimated that the semi-constant discharges from WWTPs located along the MRG basin deliver nitrogen loads of up to 1,330 kg N/day to the Rio Grande [Oelsner et al., 2007]. In dry seasons, discharges from wastewater treatment plants (WWTPs) into the Rio Grande can represent > 80% of the total river discharge. Human engineered biogeochemical hotspots: ➢ Middle Rio Grande ([Oelsner et al., 2007] and Van Horn et al. 2015) -- Synoptic sampling along the Rio Grande, its main diversions and drainage returns suggests that the agricultural system supported by the river acts as a net sink for nitrogen and phosphorus. ➢ Ricardo's lab will collect nutrient uptake (NO_3) dynamics along the Jemez-RG continuum this summer. Also, column experiments (using sand, gravel and native incubated sediments) will be run to learn how community composition and function affects uptake. ➢ Other systems - (Eastern Europe, Nile, Orange, Snake River) [*Cole et al.*, 1993, 2001; *Caraco and Cole*, 1999]

7. Discussion Where are we now in terms of understanding? What are the next steps?		
➢ In the Rio Grande, compare the lithogenic CO_2 and CH_4 contributions with the ones from shallow groundwater and in-channel processes. Convert this to CO_2 equivalent to express all in in terms of greenhouse potential ➢ Analyze the trace element contributions and their relative importance in relation with other sources from weathering in typically considered flow paths ➢ Highlight the implications of these findings for a continental budget of greenhouse gas emissions ➢ Where are we now in terms of understanding? What are the next steps? Measurement needs	The following are key data gaps: ➢ Studies of biogeochemistry of drying/re-wetting systems ➢ Data on main stem response, but no data on tributaries themselves ➢ Importance of tributary alluvial aquifer contributions to main stem flow (not to mention solutes), especially during low-flow conditions ➢ Limited number of gaged intermittent streams	➢ Hydrology ➢ Point source inputs ➢ Sinks - where are the nutrients going? • The cycle of diversion to and return from agricultural fields actually provides an ecosystem service (i.e., nutrient sequestration) to the Rio Grande, while helping increase crop yields. This cycle includes: (1) denitrification in irrigation channels and along flowpaths leaving the river and connecting irrigation channels, (2) microbial and macrophyte uptake along irrigation channels, (3) nutrient sorption onto sediments in the irrigation channel and/or in the crop field, (4) terrestrial plant uptake in crop fields, and (5) river seepage to nearby aquifers (i.e., long-term storage in groundwater compartments). ➢ Other considerations - include in one discussion paragraph? Don't stray too far from the parameters we are currently measuring continuously? • Urban runoff (nutrients, bacteria, and others) • POC • Emerging contaminants (tracers?) • Sediment loads • Land use • Major impairment issues currently occurring in other dryland river "Snake River". How does this may translate to the MRG?

Final Agenda

Arrival Day (April 17)

3:00 pm –	Participants arrive at the Sevilleta Field Station
6:00 – 7:00 pm	Dinner
7:00 – 9:00 pm	Rest and relax

First Day (April 18)

7:00 – 8:00 am	Breakfast
8:00 – 8:30 am	Introduction of Innovation Working Group, our objectives, and our topic (Cliff Dahm, Dave Van Horn, and Jesus Gomez-Velez)
8:30 – 10:00 am	Detailed introduction of participants (10 minute presentations by participants)
10:00 – 10:15 am	Break
10:15 – 12:00 pm	Detailed introduction of participants (continued)
11:00 – 12:00 pm	What research is being done or has already been done on our topic? Focus on 1) high-frequency local observations, 2) synoptic observations, and 3) data mining, assimilation, and modeling
12:00 – 1:00 pm	Lunch
1:00 – 3:00 pm	What research is being done or has already been done on our topic? (continued)
3:00 – 3:15 pm	Break
3:15 – 5:30 pm	Propose outline for review manuscript
5:00 – 6:00 pm	Break for rest in room or explore the area
6:00 – 7:00 pm	Dinner
7:00 pm –	Relax and informal discussions

Second Day (April 19)

7:00 – 8:00 am	Breakfast
8:00 – 10:00 am	Continue manuscript outline and determine who is interested in and/or best suited to address each key section. Outline a path forward, including schedule and writing assignments
10:00 – 10:15 am	Break
10:15 – 12:00 pm	Separate into breakout groups and discuss a detailed outline for each topic
12:00 – 1:00 pm	Lunch
1:00 – 3:00 pm	Separate into breakout groups and discuss a detailed outline for each topic (continued)
3:00 – 3:15 pm	Break
3:15 – 6:00 pm	Each group presents their ideas
6:00 – 8:00 pm	Each group presents their ideas (continued), schedule and writing assignments, propose a deadline, and dinner

8:00 pm – Relax and informal discussions

Third Day (April 20)

7:00 – 8:00 am Breakfast

8:00 – 10:00 am Open discussion: outline a path forward, including tentative RFPs

10:00 – 10:15 am Break

10:15 – 12:00 pm Organize and leave the Sevilleta Field Station

Final list of IWG participants

Name	Institution	Position	Areas of expertise	Email
Jesus Gomez-Velez	NMT	Faculty	Stream-aquifer interactions and hydrodynamics	jdgomez@nmt.edu
Ricardo Gonzalez-Pinzon	UNM	Faculty	Stream-aquifer interactions and artificial tracers	gonzaric@unm.edu
Cliff Dahm	UNM	Faculty	Ecology and biogeochemistry	cdahm@sevilleta.unm.edu
David Van Horn	UNM	Faculty	Ecology and biogeochemistry	vanhorn@unm.edu
Brent Newman	LANL	Researcher	Ecohydrology and environmental tracers	bnewman@lanl.gov
John Wilson	NMT	Faculty	Hydrogeology	jwilson@nmt.edu
Michael Timmons	NMBGMR	Researcher	Geology	mtimmons@nmbg.nmt.edu
Cameron Herrington	UNM	PhD Student	Water quality	cherri01@unm.edu
Sarah Miller	NMT	PhD Student	Water quality	smille00@nmt.edu
Dan Cadol	NMT	Faculty	Geomorphology and ecohydrology	dcadol@ees.nmt.edu
Brian Bergamaschi	USGS	Researcher	Biogeochemistry and instrumentation	bbergama@usgs.gov
Justin Reale	UNM	PhD Student	Water quality	justin.reale@gmail.com

NMT = New Mexico Tech, UNM = University of New Mexico, NMSU = New Mexico State University, NMBGMR = New Mexico Bureau of Geology and Mineral Resources, LANL = Los Alamos National Laboratory, USGS = US Geological Survey

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