Hyphenated Hydrology:
Multidisciplinary evolution of water resource science

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Background

Hydrology has advanced considerably as a scientific discipline since its recognized inception in the mid-20th century. Modern water resource related questions have forced adaptation from singular physical or engineering science viewpoints toward a deliberate interdisciplinary context. Over the past few decades, many of the eventual manifestations of this evolution were foreseen by prominent expert hydrologists. However, their narrative descriptions have lacked substantial quantification. This study addresses that gap by directly measuring and inspecting the words that hydrologists use to define and describe their research endeavors.

Hypotheses

1.) Hydrology as a scientific discipline is moving toward interdisciplinarity.
2.) Certain sub-disciplines of hydrology, like Socio-hydrology, are increasing in popularity.
3.) We can use frequently used terms in titles to observe and predict trends in hydrology.

Methodology

1. Journal Selection → Journal Titles

Table 1. Top 10 water resources journals, ranked by 2015 impact factor (Thomson Reuters, 2016), including year of the first issue and total number of citations.

Journal title	Impact factor	First issue (year)	Total citations
Water Research	5.99	1967	61,285
Desalination	4.41	1966	29,723
Advances in Water Resources	4.35	1977	8,156
HESS	3.99	1997	10,606
WRR	**3.79**	**1965**	**42,682**
JoH	3.04	1963	37,044
Environmental Toxicology	2.87	1986	3,082
Hydrological Processes	2.77	1986	16,884
Catena	2.61	1974	7,343
Agricultural Water Management	2.60	1976	8,901

2. Term Frequencies and Categorization

Frequently used terms = appear in WRR titles (~17k) at least 100 times.

Table 2. Functional, non-functional categories and the sub-disciplines that fall under each.

Functional Categories	Non-Functional Categories
Catchment-hydrology	Methods
Hydro-geology	Scale
Hydro-meteorology	Ambiguous
Contaminant-hydrology	
Socio-hydrology	
Hydro-climatology	
Eco-hydrology	

3. Evolution of Sub-disciplines

1. Timeseries of categorical proportion
2. LOWESS smoothing trend
3. Turn Points → Mean Turn Point (1989)
   Pre-modern and modern hydrology
4. Linear Models

Are hydrologic sub-disciplines statistically significantly decreasing or increasing over time?

4. Term-to-term Association Networks

Frequent Term-Frequent Term Networks
Weighted network metrics to analyze evolution of network between pre- and post-1989.
Term-to-Any-Other-Word Association
Most frequently used term in each category (7)

Results

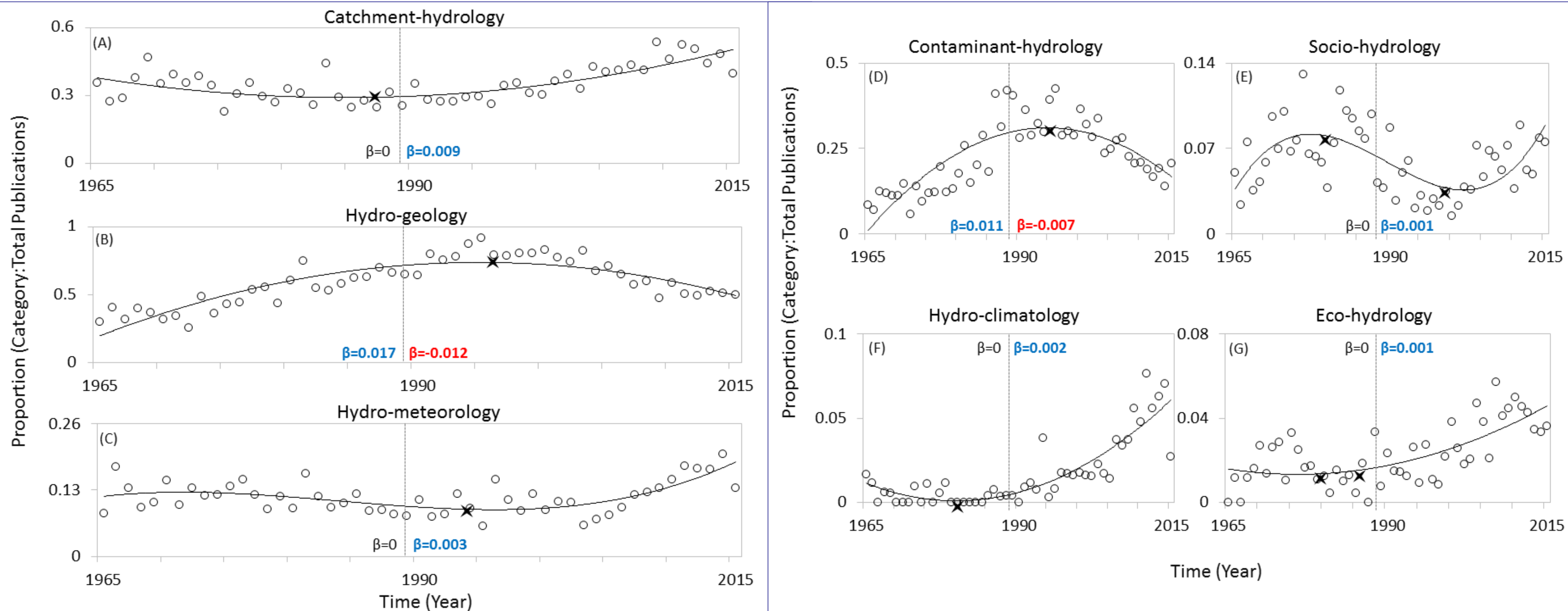### Evolution of Sub-disciplines

Figure 1A-G. Time series evolution of Foundational (A-C) and Evolutionary Hydrology (D-G) as determined by terms used in WRR publication titles. A LOWESS curve with a 2/3 smoothing value was applied, and turn points (black crosses) were determined for each category, or sub-discipline. The mean turn point, 1989 (dashed vertical line), serves as the dividing year between the two time periods. Linear regression slopes (β) are shown for each period.
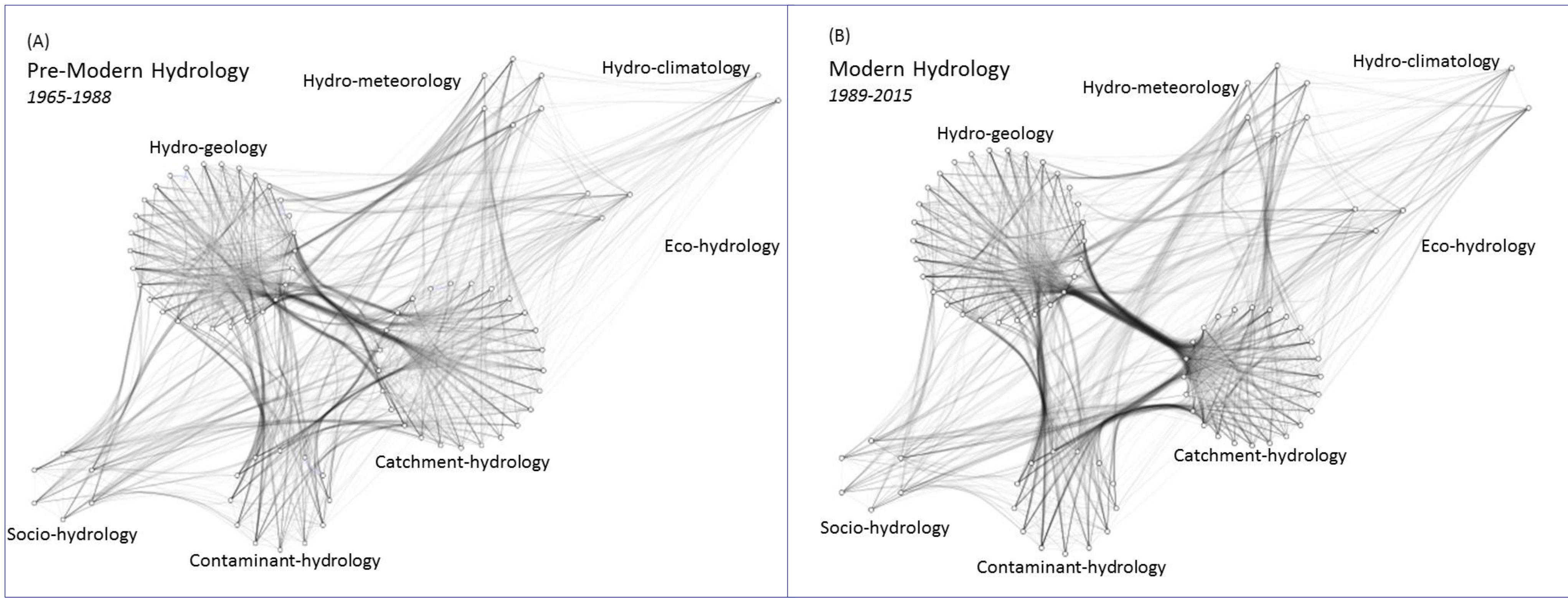
Term Association Networks

Figure 2A-B. Weighted word association network, with connections normalized by the number of total publications in each time period. All functional terms are organized into a circular layout respective to their corresponding categories.
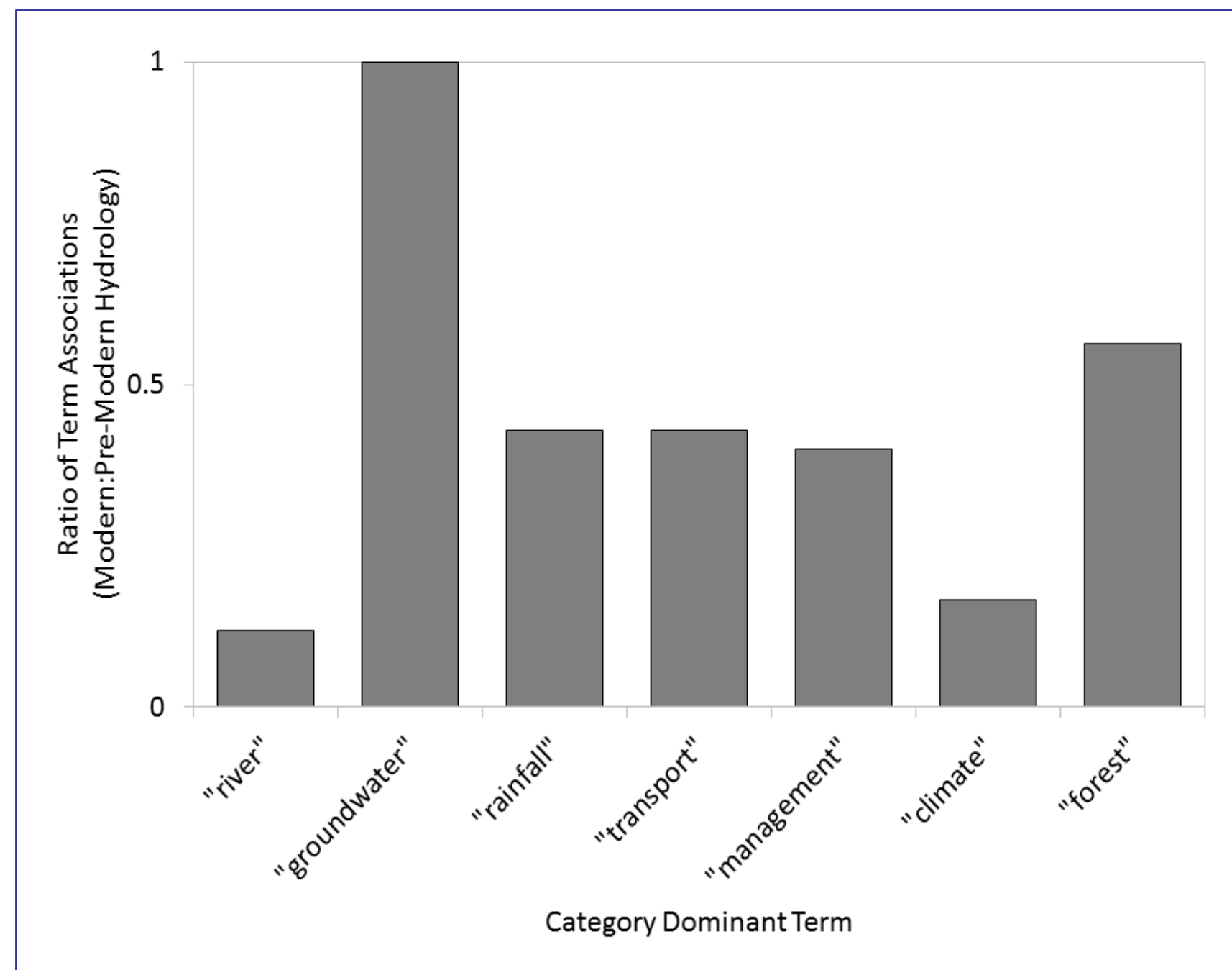

Figure 3. The ratio between modern and pre-modern hydrology of the number of associations between dominant terms in each functional category and any other word in WRR titles.

Table 3. Changes (Δ) in weighted topological metrics for the categorized major sub-disciplines of hydrology between the time periods of pre-modern (1965-1988) and modern (1989-2015) hydrology. Changes in degree, betweenness centrality and closeness centrality demonstrate the evolution of category positioning in the term-term word association network.

Category	ΔBetweenness (%)	ΔCloseness (%)	Node Degree (pre-modern)	Node Degree (modern)
Catchment-hydrology	**200**	103	6	6
Hydro-geology	-58	76	6	6
Hydro-meteorology	-100	55	6	6
Contaminant-hydrology	0	71	6	6
Socio-hydrology	0	22	**5**	**6**
Hydro-climatology	0	239	**5**	**6**
Eco-hydrology	0	62	6	6

Interpretations and Implications

Main Conclusions:
- Catchment-hydrology, Hydro-meteorology, Socio-hydrology, Hydro-climatology and Eco-hydrology all experience a **statistically significant increase** in modern hydrology.
- Hydro-geology and Contaminant-hydrology **decrease**.
- Catchment-hydrology gains the **most relative influence** on the dispersal of information throughout the network.
- Frequently used terms have **fewer strong associations** in modern hydrology.

Hydrology is moving toward increasing **interdisciplinarity**. This multi-faceted perspective allows for broad scale, practical application.

Future Analyses

Potential for future studies of hydrology as a scientific discipline:
- More journals
- Abstracts (or full text) in addition to article titles

Ideally...
- All published papers marked as "water resources" in Web of Science.

Principal References

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