THE FEWSION DATABASE™ VERSION 1.0

Dataset Documentation and Guide
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For in-line citations, please specify within the text whether you are citing the whole database or a specific data layer.

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Language

The FEWSION v. 1.0 Database, processing code, and all supported reference material at present are available in English only.

Revision History

March 4th, 2020: Added a description of the flow metrics: total inflow, total outflow, inflow rank, and outflow rank. The glossary was updated to include the terms 'Total Outflows', 'Total Inflows', 'Inflow Rank', and 'Outflow Rank', which are metrics that were added to the FEW-View™ visualization system.

FEWSION™ Database Overview

The integration of disparate food, energy, and water datasets to create a uniform model of a food-energy-water (FEW) system faces numerous methodological and analytical challenges. Chief among these challenges are data quality, availability, comprehensiveness, and concordance.

The FEWSION Project addresses these challenges to modeling integrated FEW systems through a data fusion and analysis computing workflow to produce a database that describes the United States FEW system, called the FEWSION Database™. The FEWSION Database™ is a spatially- and temporally-detailed input-output database describing the FEW system of communities in the United States along with other commodity flows, their resource footprints, and resource dependencies. This data documentation and guide is intended for use in conjunction with the FEWSION Database™ and other associated data products. The information in this document describes the coverage, methods, processing techniques, statistical methods, schemas, source material, file structure, and file formats for the FEWSION™ Database.

The goal of the FEWSION Project is to produce FEW data for researchers, decision-makers, and the public. Therefore, the FEWSION Project has made the data contained in the FEWSION™ Database available to the public through an online visualization system called FEW-View™, which allows users to visualize U.S. state- and county-level FEW system connections in real-time.

FEWSION Database™ v.1.0 Data Coverage

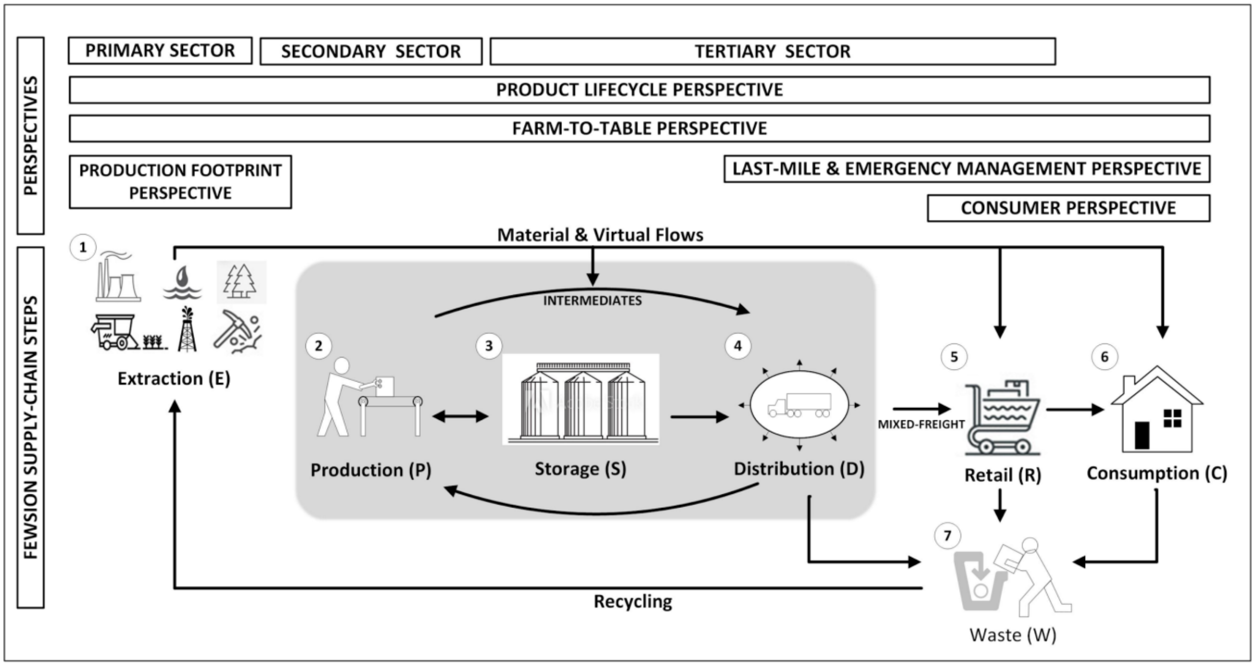
Temporal Coverage

The temporal coverage of the FEWSION Database™ version 1.0 is a single year in the 2010-2012 period. Reference time periods for this version, and subsequent releases, are dictated by source data availability and the time resolution those datasets. The 2010-2012 period was dictated by the availability of Commodity Flow Survey Produced by United States Census Bureau (U.S. Census Bureau, 2019a) and the Freight Analysis Framework (FAF) published by Oak Ridge National Laboratories and the U.S. Department of Transportation (Hwang, et al. 2016) addition to national water use data produced by the United States Geological Survey (Maupin et al., 2014). As these source data are annual data products, the version 1.0 database is an annual data product, wherein the year corresponds to a typical year during the period 2010-2012. Depending on the layer chosen, the year may be 2010 or 2012 or may not be specified with precision.

Economic Coverage

This database is synthesized from commodity flow data, electricity flow models, and water flow models. As such, the economic coverage of this database includes the production of food, energy, water; commodities that utilize food, energy, water; and the distribution of food, energy, and water resources, along with other commodity flows and wastes. Services are not included in this version of the data. A generic food, energy, water supply chain described by the data in the FEWSION Database™ v.1.0 is shown in Figure 1.

Figure 1. The seven general FEW supply chain steps captured by the FEWSION Database™; a flow in the database corresponds to any one of these seven steps (Ruddell et al., 2019, In Press). Image reproduced with permissions of the authors.



The FEWSION supply chain steps that are shown in Figure 1 are detailed in Table 1. While a general FEWSION supply chain is shown in Figure 1, specific supply chain diagrams have been developed for multiple food, energy, and water supply chains. These supply chain diagrams and the interaction between the FEW supply chain and infrastructure networks are contained in a companion FEW textbook chapter (Ruddell et al., 2019, In Press).

Table 1. FEWSION Supply Chain Steps and Codes

Supply Chain Step	Supply Chain Code	Description
Extraction	E	Extraction from the environment, at the source, primary industry only.
Production	P	Manufacturing, processing, value-add processing, business to business service sector flows.
Storage	S	Storage in the form of mass stockpiling, hubs, reserves.
Distribution	D	Transportation, warehousing, last mile distribution.
Retail	R	Retail in the form of last mile delivery.
Consumption	C	Consumption by human end users, not companies or producers.
Waste	W	Waste from both producers and consumers, including recycling and reuse

In the United States, businesses and establishments responsible for both direct and indirect FEW flows at each of the supply chains steps located in Table 1 can be classified with the North American Industry Classification System (NAICS, Office of Management and Budget, 2017). NAICS codes included in the FEWSION Database™ v. 1.0 database are shown in Table 2. Please refer to the Office of Management and Budget and U.S. Census for a full description of the North American Industry Classification System.

Table 2. NAICS Codes Included in the FEWSION v. 1.0 Database

NAICS Code	NAICS Title
11	Agriculture, Forestry, Fishing, and Hunting
211111	Crude Petroleum and Natural Gas Extraction
212	Mining (except Oil and Gas)
2211	Electric power generation, transmission and distribution
221210	Natural Gas Distribution
221310	Water Supply and Irrigation Systems
221320	Sewage Treatment Facilities
311	Food Manufacturing
312	Beverage and Tobacco Product Manufacturing
313	Textile Mills
314	Textile Product Mills
315	Apparel Manufacturing
316	Leather and Allied Product Manufacturing
321	Wood Product Manufacturing
322	Paper Manufacturing
323	Printing and Related Support Activities
324	Petroleum and Coal Products Manufacturing
325	Chemical Manufacturing
326	Plastics and Rubber Products Manufacturing
327	Nonmetallic Mineral Product Manufacturing
331	Primary Metal Manufacturing
332	Fabricated Metal Product Manufacturing
333	Machinery Manufacturing
334	Computer and Electronic Product Manufacturing
335	Electrical Equipment, Appliance, and Component Manufacturing
336	Transportation Equipment Manufacturing
337	Furniture and Related Product Manufacturing
339	Miscellaneous Manufacturing
4231	Motor Vehicle and Motor Vehicle Parts and Supplies Merchant Wholesalers
4232	Furniture and Home Furnishing Merchant Wholesalers
4233	Lumber and Oher Construction Materials Merchant Wholesalers
4234	Professional and Commercial Equipment and Supplies Merchant Wholesalers
4235	Meal and Mineral (except Petroleum) Merchant Wholesalers
4236	Household Appliances and Electrical and Electronic Goods Merchant Wholesalers
4237	Hardware, and Plumbing and Heating Equipment and Supplies Merchant Wholesalers
4238	Machinery, Equipment, and Supplies Merchant Wholesalers
4239	Miscellaneous Durable Goods Merchant Wholesalers
4241	Paper and Paper Product Merchant Wholesalers
4242	Drugs and Druggists'' Sundries Merchant Wholesalers

NAICS Code	NAICS Title
4244	Grocery and Related Product Merchant Wholesalers
4245	Farm Product Raw Material Merchant Wholesalers
4246	Chemical and Allied Products Merchant Wholesalers
4247	Petroleum and Petroleum Products Merchant Wholesalers
4248	Beer, Wine, and Distilled Alcoholic Beverage Merchant Wholesalers
4249	Miscellaneous Nondurable Goods Merchant Wholesalers
4541	Electronic Shopping and Mail
45431	Fuel Dealers
486210	Pipeline Transportation of Natural Gas
4931	Warehousing and Storage
551114	Corporate, Subsidiary, and Regional Managing Offices
4243	Apparel, Piece Goods, and Notions Merchant Wholesalers
5111	Newspaper, Periodical, Book, and Directory Publishers
562111	Solid Waste Collection

The public extracts of the FEWSION Database™ v. 1.0 do not differentiate commodity flows by NAICS codes, so a commodity flow between an origin and a destination could involve one or multiple NAICS codes from Table 2 and as a result one or multiple supply chain steps from Table 1. Therefore, a commodity flow could incorporate the actual production of a food, energy, or water resource in addition to the distribution of a food, energy, or water resource.

The direct and indirect flow of food, energy, or water resources are estimated using commodity flows between an origin and destination. Commodities are classified by the Standard Classification of Transported Goods version 2 (SCTG2; U.S. Census Bureau, 2019b). The SCTG2 system is utilized by the Commodity Flow Survey Produced by United States Census Bureau (U.S. Census Bureau, 2019a) and the Freight Analysis Framework (FAF) published by Oak Ridge National Laboratories and the U.S. Department of Transportation (Hwang, et al. 2016). However, the SCTG2 system does not contain commodity codes for water or electricity, or for select other commodities, so an augmented classification system is utilized for the FEWSION Database™ v. 1.0.

The FEWSION Commodity Code System (FCCS) is a 7-digit code that contains information on the sector, subsector, and commodity that flows between an origin and destination the FEWSION Database™ v. 1.0. The first digit of an FCCS code is the broadly scoped FEW sectors of a commodity flow. Sectors are the highest level of aggregation in FCCS (Table 3).

Table 3. FCCS Sector Codes and Names

FEWSION Sector Code	FEWSION Sector name
1	Food
2	Energy
3	Water
4	Industrial
5	Waste
6	Services

The next level of FCCS, and the next three digits (positions two through four in the FCCS code), is the subsector, a set of thematically- and functionally-related commodities within a sector (Table 4). The commodity flows within a subsector may be aggregated using a common unit of measure, such as GWh for energy units. Each FCCS subsector typically corresponds to two or three supply chain steps (Figure 1). For example, FEWSION Subsector 460, which covers Mixed Freight, typically corresponds to the retail and consumer supply chain steps (and not to the production of food or consumer goods at farms and manufacturing facilities).

Table 4. FEWSION Subsector Codes

FEWSION Subsector Code	FEWSION *Subsector* Name	FEWSION Subsector Common Unit	FEWSION Supply Chain Steps
100	Agricultural Products, all	tonne	E, P, S, D
110	Food & Beverages, all	tonne	P, S, D
130	Alcohol & Tobacco, all	tonne	E, P, S, D
200	Electrical Energy, all	GWh	P, D, R, C
210	Fossil Fuels, all	GWh	E, P, S, D, R, C
300	Fresh Water, All	Mm3	P, D, R, C
310	Potable Water, all	Mm3	P, D, C
320	Saline Water, All	Mm3	P, D, C
330	Waste Water, all	Mm3	W, P, D, C
340	Reclaimed Water, all	Mm3	P, D, C
400	Mining Products, all	tonne	E, P, S, D
410	Chemical Products, non-pharmaceutical, all	tonne	P, S, D, R, C
415	Pharmaceuticals, all	tonne	P, S, D, R, C
420	Raw wood, all	tonne	E, P, S, D
430	Finished Materials, all	tonne	P, S, D
440	Machinery, all	tonne	P, S, D
445	Precision, all	tonne	P, S, D
450	Vehicles, all	tonne	P, S, D
455	Mfg. Prods., all	tonne	P, S, D
460	Mixed Freight, All	tonne	R, C
565	Waste, All	tonne	W, P, D
680	Services, All	dollar	P, D, R, C

It should be noted that while many of the source datasets that are ingested by the various FEWSION processing algorithms are reported in Imperial units, the FEWSION Database utilizes units according to the International System of Units (SI Units). However, flows for specific commodities may be categorized by other supplementary 'common' units beyond SI Units – for example, barrels of oil or million cubic feet of natural gas.

The final level of a commodity in the FCCS is the "SCTG+FEWSION" commodity code (Table 5). The SCTG+FEWSION commodity code is a three-digit augmented SCTG2 commodity code that adds in commodities that are not in the SCTG2 system (positions five through seven in the FCCS code). Like subsectors, the SCTG+FEWSION commodity codes usually correspond to a specific subset of two or three supply chain steps. Finally, each commodity at the SCTG+FEWSION level is a part of a single

FEWSION Subsector. SCTG+FEWSION data layers can be “rolled up” into FEWSION Subsector Commodity Roll Up data layer using a common unit (Table 4).

Table 5.The SCTG+FEWSION Commodity Code System

Commodity Code	Commodity Name	Units List	FEWSION Supply Chain Steps
1	Live animals/fish	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
2	Cereal grains	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
3	Other ag prods.	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
4	Animal feed	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
5	Meat/seafood	tonne, dollar, virtual water withdrawals and consumption	P, S, D
6	Milled grain prods.	tonne, dollar, virtual water withdrawals and consumption	P, S, D
7	Other foodstuffs	tonne, dollar, virtual water withdrawals and consumption	P, S, D
8	Alcoholic beverages	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
9	Tobacco prods.	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
10	Building stone	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
11	Natural sands	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
12	Gravel	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
13	Nonmetallic minerals	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
14	Metallic ores	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
15	Coal	GWh, barrel, tonne, dollar	E, P, S, D, C
16	Crude petroleum	GWh, barrel, tonne, dollar	E, P, S, D
17	Gasoline	GWh, barrel, tonne, dollar	P, S, D, R, C
18	Fuel oils	GWh, barrel, tonne, dollar	P, S, D, R, C
19	Coal-n.e.c.	tonne, dollar, virtual water withdrawals and consumption	P, S, D, R, C
20	Basic chemicals	tonne, dollar, virtual water withdrawals and consumption	P, S, D, R, C
21	Pharmaceuticals	tonne, dollar, virtual water withdrawals and consumption	P, S, D, R, C
22	Fertilizers	tonne, dollar, virtual water withdrawals and consumption	P, S, D, R, C
23	Chemical prods.	tonne, dollar, virtual water withdrawals and consumption	P, S, D, R, C
24	Plastics/rubber	tonne, dollar, virtual water withdrawals and consumption	P, S, D, R, C
25	Logs	tonne, dollar, virtual water withdrawals and consumption	E, P, S, D
26	Wood prods.	tonne, dollar, virtual water withdrawals and consumption	P, S, D
27	Newsprint/paper	tonne, dollar, virtual water withdrawals and consumption	P, S, D
28	Paper articles	tonne, dollar, virtual water withdrawals and consumption	P, S, D
29	Printed prods.	tonne, dollar, virtual water withdrawals and consumption	P, S, D
30	Textiles/leather	tonne, dollar, virtual water withdrawals and consumption	P, S, D
31	Nonmetal min. prods.	tonne, dollar, virtual water withdrawals and consumption	P, S, D
32	Base metals	tonne, dollar, virtual water withdrawals and consumption	P, S, D
33	Articles-base metal	tonne, dollar, virtual water withdrawals and consumption	P, S, D
34	Machinery	tonne, dollar, virtual water withdrawals and consumption	P, S, D
35	Electronics	tonne, dollar, virtual water withdrawals and consumption	P, S, D
36	Motorized vehicles	tonne, dollar, virtual water withdrawals and consumption	P, S, D
37	Transport equip.	tonne, dollar, virtual water withdrawals and consumption	P, S, D
38	Precision instruments	tonne, dollar, virtual water withdrawals and consumption	P, S, D
39	Furniture	tonne, dollar, virtual water withdrawals and consumption	P, S, D
40	Misc. Mfg. prods.	tonne, dollar, virtual water withdrawals and consumption	P, S, D
41	Waste/scrap	tonne, dollar, virtual water withdrawals and consumption	W, P, D
43	Mixed freight	tonne, dollar, virtual water withdrawals and consumption	R, C
100	Electricity	GWh, MW	P, D, R, C
196	Natural Gas	mcf, GWh, dollars, tonne	P, D, R, C
800	Services	dollar	P, D, R, C
999	Water	Mm3	W, P, D, C

Additionally, commodities in the FEWSION Database™ v. 1.0 can be assigned to and aggregated up to water use sectors (*s*): agriculture, including irrigation; livestock and aquaculture; mining; industrial; and domestic (Maupin et al., 2014).

The flow of FEW resources can be measured by multiple units and trade flow analytics can be calculated to characterize the flow FEW resources between an origin and destination. The SCTG+FEWSION Units are defined in Table 6.

Table 6. FEWSION Commodity Code System (FCCS) Unit Definitions

SCTG+FEWSION Unit	Definition
barrel	Barrels (b) are a common unit of volume for measuring liquid fuels production and consumption. A barrel is approximately 42 gallons.
dollar	A unit of currency equivalent to United States Dollars for the year 2012. FEWSION typically displays currency in millions of dollars ($MM).
GWh	Gigawatt hours (GWh) are a unit of energy for measuring large amounts of energy production and consumption.
mcf	Million cubic feet (mcf) is a common unit of volume for measuring natural gas production and consumption.
Mm^3	Million cubic meters (Mm^3) is a common unit to measure large volumes of water.
MW	Megawatts (MW) is a unit of power for measuring large amounts of power production and consumption.
tonne	A unit of mass equivalent to a metric tonne (t). FEWSION typically displays mass units in thousand metric tonnes (kt)
VW Consumption (Mm^3)	Virtual water consumption in million cubic meters per year ($Mm^3\ yr^{-1}$).
VW Withdrawals (Mm^3)	Virtual water withdrawals in million cubic meters per year ($Mm^3\ yr^{-1}$).
WSI	WSI is a water scarcity index that measures how much water is consumed relative to how much is available. A WSI closer to 1 indicates that water consumption is close to water availability.
IWSI	IWSI is a measure of water scarcity in a state or county's supply chain. An IWSI closer to 1 indicates that water consumption in a supply chain is close to water availability in a supply chain.
IWSI Contribution	IWSI contribution is a measure of an individual county's contribution to water scarcity in a state or county's supply chain.
BWF - Withdrawals (Mm^3)	A state or county's blue water footprint (BWF) is measured as a volume of water (Mm^3). It's equal to a state or county's water use plus its virtual water balance. Virtual water balance is equivalent to virtual water inflows minus virtual outflows. For the BWF of withdrawals, the BWF is calculated on a withdrawal-basis where all water that is withdrawn is consumed.
BWF - Consumption (Mm^3)	A state or county's blue water footprint (BWF) is measured as a volume of water (Mm^3). It's equal to a state or county's water use plus its virtual water balance. Virtual water balance is equivalent to virtual water inflows minus virtual outflows. For the BWF of withdrawals, the BWF is calculated on a consumption-basis, where a fraction of the water withdrawn is returned to the environment.
Shannon Diversity Index (SI)	Shannon Diversity Index is an index to measure supply chain diversity, or resilience. A Shannon Diversity Index closer to 1 indicates a more diverse supply chain where many sources are relied upon equally. A Shannon Diversity Index closer to 0 indicates that a supply chain is dominated by a handful of sources.

All data tables in this section describing the FEWSION Commodity Code System, along with all tables in this data documentation guide, are located in a companion reference spreadsheet (Rushforth, R.R., and Ruddell B.L, 2019. FEWSION Commodity Code System and Data Tables. URL: https://www.dropbox.com/s/gk23dfqe8akl83n/FEWSION_Commodity_Code_Workbook.xlsx?dl=0).

Geographic Coverage

The FEWSION Database™ v. 1.0 is U.S.-centric by virtue of its representation of spatial units using U.S. states and counties. There are flows related to the international import and export of FEW system resources, but these flows are U.S.-centric as well. In other words, international flows to and from locations within the U.S. are included, but flows between two non-U.S. countries, such as a trade flow from Canada to Mexico, are not included. The U.S.-centric nature of the current version of the database is an artifact of the primary source datasets being largely produced by the U.S. Federal government's agencies.

Counties are codified by the Federal Information Processing Standards (FIPS); this version of the database utilizes the 2016 county FIPS code standard (U.S. Census Bureau, 2017). In the 2016 county FIPS code system there are 3,142 U.S. counties and county equivalents. Building up from the county-level, the intermediate U.S. geographic unit is the commodity flow zone, which is centered around U.S. metropolitan and census statistical areas (Southworth et al., 2010; Hwang et al., 2016). Utilizing the commodity flow zone codification system contained in the Commodity Flow Survey Produced by United States Census Bureau (U.S. Census Bureau, 2019a), the Freight Analysis Framework (FAF) published by Oak Ridge National Laboratories and the U.S. Department of Transportation (Hwang, et al. 2016)., the U.S. is divided into 132 zones (hereafter called FAF zones) including metropolitan areas, remainders of states, and entire states. Finally, the coarsest geographic unit in the FEWSION v. 1.0 Database is the state-level, which utilizing the 2016 state FIPS code standards (flows to global nations and regions are also included).

Globally, this database organizes the world into eight global regions. The global region grouping and codification system is the same as the one used by the Freight Analysis Framework (FAF) published by Oak Ridge National Laboratories and the U.S. Department of Transportation (Hwang, et al. 2016). These eight global regions are Canada, Mexico, Rest of Americas, Europe, Africa, Southwest and Central Asia, Eastern Asia, Southeast Asia and Oceania (Hwang, et al. 2016).

It should be noted that this version of the database does not contain data for U.S. territories because the source datasets categorize these geographic areas into foreign zones. For example, Puerto Rico is classified to be part of the Rest of Americas global zone and American Samoa and Guam are classified to be part of the Southeast Asia and Oceania global zone (Hwang, et al. 2016).

Key Methods References

Below is a list of key references for methods and source data for the FEWSION Database™ v. 1.0.

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Methods

The methods to derive county-to-county commodity flows and embedded environmental attribute flows are mostly covered by Rushforth and Ruddell (2018), which covers an evolutionary ancestor to the FEWSION Database™, the National Water-Economy Database (NWED). This methods section has been adapted from Rushforth and Ruddell (2018). A full explanation of methodological and source data differences is located in the "Changes Between NWED v 1.1 and the FEWSION Database™ v. 1.0" at the end of this document.

Commodity Flow Methods

Matrix Notation and Terminology

The general form of a trade linkage (*T*) in the FAF database is a commodity (*c*) that flows from an origin FAF zone (O_o) to a destination FAF zone (D_d) over a domestic transport mode (k_{dom}) represented as tons (*t*), currency (*$*), and ton-miles (*tm*), where *o* and *d* are indices for the 132 FAF zones. Additionally, each *c* is associated with a broader economic sector (*s*) that corresponds to the USGS water withdrawal categories. International imports and exports originate from and terminate at one of 8 international origin (O_I) and destination (D_E) zones via an international transport mode (k_{int}). For an import, a *c* is produced in an international region (O_I) and flows through a port of entry (O_o) and then to a D_d of final consumption. For an export, a *c* is produced in a O_o and then exits the U.S. through a port of exit (D_d) for consumption in an international region (D_E). Domestic, import and export trades can be also classified by a trade type index (*f*) Therefore, a trade linkage of a commodity in terms of *t, $,* and *tm* between an origin zone and destination, which may not include a foreign region, can be represented as $T_{O_I,O_o,D_d,D_E,k_{int},k_{dom},c,f}(t,\$,tm)$. This database builds upon FAF by further disaggregating O_o and D_d to origin (I_n) and destination counties (J_m), respectively, and by adding virtual water, represented generally as (*VW*). Each row in this database is trade linkage, $T_{O_I,O_o,I_n,J_m,D_d,D_E,k_{int},k_{dom},c,f}$, with a corresponding flow of *t*, *$*, *tm*, and *VW* that can be aggregated by any combinations of index $O_I \rightarrow f$. However, we drop all of these subscripts for a simpler derivation of this database disaggregation algorithm. This database retains data for transport mode, tons, currency, and ton-miles because there are use cases outside of virtual water accounting that may utilize mode-specific data or data on *$* or *tm* flows (extracts may not include all of these units and details).

Commodity Flow Disaggregation Method

The disaggregation method proceeds from the origin side (*O*), disaggregating to origin counties (*I*), and then to the destination side (*D*), disaggregating to destination counties (*J*). Each *O* contains a distinct set of one or multiple origin counties (I_n), where $I_n \in O,$ and each *D* contains a distinct set of multiple destination counties (J_m), where $J_m \in D.$ Further, each county (*n or m*) within each *O* and *D* has a unique production factor (*PF*) and attraction factor (*AF*) for each economic sector and, where supported by data, each commodity produced in that county. Each *I* and *J* can be defined as a distinct set of unitless *PF* or *AF* factors for each commodity, $\{I_n\text{: } PF_{c1}, PF_{c2}, \ldots, PF_{c43}\}$ and $\{J_m\text{: } AF_{c1}, AF_{c2}, \ldots, AF_{c43}\}$, repectively. Therefore, any O_o or D_d can be represented by a column vector of PF_c or AF_c corresponding to the I_n or J_m that belong to O_o or D_d. Given that the PF_c or AF_c define the proportion of production capacity and demand attraction a county has within a O_o or D_d, the sum of the PF_c or AF_c for a given O_o or D_d must be equal to 1 to conserve mass. Therefore, for a given commodity (*c*) with an associated sector (s) and *t*, *$*, and *tm* over 8 transport modes, *k*,

(1) $O_{o,c} = \begin{bmatrix} I_{1PF_c,O_{o,c}} \\ I_{2PF_c,O_{o,c}} \\ \vdots \\ I_{nPF_c,O_{o,c}} \end{bmatrix}$ or $D_{d,c} = \begin{bmatrix} J_{1AF_c,D_{d,c}} \\ J_{2AF_c,D_{d,c}} \\ \vdots \\ J_{mAF_c,D_{d,c}} \end{bmatrix}$, where $\sum_n O_o = 1$ and $\sum_m D_d = 1$.

Disaggregating production from a O_o that contains counties $I_{1 \to n}$, O = {$I_1, I_2, ..., I_n$} for a *c* proceeds as follows:

$$(2)\ T_{O_o,D_d,c} \times \begin{bmatrix} I_{1PF_c,O_{o,c}} \\ I_{2PF_c,O_{o,c}} \\ \vdots \\ I_{nPF_c,O_{o,c}} \end{bmatrix} = \begin{bmatrix} T_{I_1,D_d,c} \\ T_{I_2,D_d,c} \\ \vdots \\ T_{I_n,D_d,c} \end{bmatrix}$$

Solving Equation 2 over all O_o for each commodity disaggregates FAF zone commodity outflows to the county-level – from 132 origin FAF zones (O_o) to 3,142 origin counties (I_n). A quality control is performed to ensure that no additional mass, currency, or ton-miles are produced for all commodities across all O_o. After the production-side disaggregation, 3,142 origin counties are linked with 132 FAF zone destinations via trade of commodities (c).

Similarly, the goal of the demands-side disaggregation is to disaggregate flows to 132 FAF zones to 3,142 counties; however, instead of the relative abundance of industries that produce a specific commodity to disaggregate production, population is used as a simple measure of a county's attraction (demand) of a commodity within a FAF zone. It follows that disaggregation on demand side of the O-D trade linkage follows a similar process.

For a D_d that contains counties J_1 to J_n, $D_d = \{J_1, J_2, ..., j_n\}$ for *g* produced in an origin county, I_n, disaggregation proceeds as follows:

$$(3)\ T_{I_n,D_d,c} \times \begin{bmatrix} J_{1AF_{c,D_d}} \\ J_{2AF_{c,D_d}} \\ \vdots \\ J_{nAF_{c,D_d}} \end{bmatrix} = \begin{bmatrix} T_{I_n,J_1,c} \\ T_{I_n,J_2,c} \\ \vdots \\ T_{I_n,J_m,c} \end{bmatrix}$$

At this point, quality control is performed to ensure that no new mass, currency, or ton-miles are erroneously introduced for all commodities across all O_o and D_d. Performing this disaggregation step across all I_n disaggregates the flows of *c* in terms of *t*, *$*, and *tm* to be between 3,142 origin counties and 3,142 destinations counties over 8 potential transport modes, *k*.

International flow disaggregation follows the same process; however, the 8 world regions are not disaggregated further and import flows are not further disaggregated into surface water and groundwater. After, import and export flows are disaggregated each world region is connected via a production of consumption trade flow with one of 3,142 U.S. counties flowing through a port of entry or exit.

Commodity Water Footprints and Virtual Water Flows using Trade Flows

Economic sectors (*s*) in the database were aligned with water withdrawal sectors (WU_s) using the detailed Standardized Classification of Transported Goods (SCTG) definitions of commodity groups (U.S. Census Bureau, 2006; Dang et al., 2015). County-specific, sector-level water intensities ($WI_{I_n,s,W_{Total}}$) were calculated as the quotient of county-specific, sector-level water withdrawals ($WU_{I_n,s,W_{Total}}$) and county-level, sector-specific commodity production ($\sum_{D_d,c} T_{I_n,D_d,c}$) and have the units Mm^3 t^{-1}. In the initial step of calculating $WI_{I_n,s,W_{Total}}$, groundwater and surface water withdrawals are summed to a total sector-level water withdrawal figure for each county ($WI_{I_n,s,W_{Total}}$). Virtual water flows are disaggregated back to groundwater and surface water fractions in a later step.

(4) $$WI_{I_n,s,W_{Total}} = WU_{I_n,s,W_{Total}} / \textstyle\sum_{D_d,c} T_{I_n,D_d,c}$$

The resulting $WI_{I_n,s,W_{Total}}$ can be interpreted as the average withdrawal-based water intensity of sector-level production. Next, $WI_{I_n,s,W_{Total}}$ were multiplied by the corresponding $T_{I_n,J_m,c}$ to arrive at the virtual water flows by county and commodity by transport mode.

(5) $$VW_{I_n,J_m,c,W_{Total}} = WI_{I_n,s,W_{Total}} \times T_{I_n,J_m,c}$$

The $VW_{I_n,J_m,c}$ that results from this process assigns water withdrawals to a commodity based on the tons of a *c* within a county according to the disaggregated FAF data.

For notational clarity, when $VW_{I_n,J_m,c,W_{Total}}$ is summed for all unique origin counties (I_n) the term is simplified to $VW_{Out,Total}$. Conversely, when summed for all unique destination counties (J_m) the term is simplified to $VW_{In,Total}$. Additionally, $WU_{I_n,s,Total}$ summed over all sectors for all unique counties becomes $WU_{W_{Total}}$. This notation also holds true for consumption-based virtual water flows.

Minimum (*Min*), median (*Med*), and high (*Max*) water consumption scenarios for each sector in each county were determined by multiplying $WU_{I_n,s,W}$ by the corresponding sector-level minimum, median, and high consumption coefficients developed by the USGS (Shaffer and Runkle, 2007). Only the methodology for *Med* consumption scenario is shown below since both the *Min* and *Max* consumption scenarios follow an identical calculation process.

(6) $$WI_{I_n,s,CU_{Med,Total}} = (WU_{I_n,s,W_{Total}} \times CU_{Med,S}) / \textstyle\sum_{D_d,c} T_{I_n,D_d,c}$$

(7) $$VW_{I_n,J_m,c,CU_{Med,Total}} = WI_{I_n,s,CU_{Med,Total}} \times T_{I_n,J_m,c}$$

Owing to these consumption coefficients being developed for the Great Lakes Region, and climatically similar states, the consumption-based virtual water flows in NWED serve as placeholders until region- or county-specific and sector-level water consumption coefficients have been developed for the U.S.

Since the USGS water withdrawal data contains data on groundwater and surface water withdrawals for each sector within each county, $VW_{I_n,J_m,c,CU_{Max,Total}}$, $VW_{I_n,J_m,c,CU_{Med,Total}}$, and $VW_{I_n,J_m,c,CU_{Min,Total}}$ are split into groundwater and surface water components be multiplying each by the county-specific, sector-specific groundwater withdrawal percentage ($GW_{I_n,s,pct}$) and surface water percentage ($SW_{I_n,s,pct}$). The process is shown below for $VW_{I_n,J_m,c,s,t,k,CU_{Max}}$.

(8) $$VW_{I_n,J_m,c,CU_{Max,SW}} = VW_{I_n,J_m,c,CU_{Max,Total}} \times SW_{I_n,s,pct}$$

(9) $$VW_{I_n,J_m,c,CU_{Max,GW}} = VW_{I_n,J_m,c,CU_{Max,Total}} \times GW_{I_n,s,pct}$$

After this step, there is a final mass balance check to ensure the database's freight totals match underlying FAF data and that water data match underlying USGS data.

Power Flow Estimation and Disaggregation

The power flow data used in this database is an existing published dataset produced using the Regional Energy Deployment System (ReEDS), which is a long-term power flow model to evaluate capacity-expansion, technology deployment, and infrastructure deployment in the contiguous U.S (Macknick et al., 2015; Eurek et al., 2016; Cohen et al., 2014). Only for the electrical power production sector, NREL data on water withdrawal and consumption data were used instead of USGS water withdrawal data to estimate the water withdrawal and consumption associated with power generation and flow (Macknick et al., 2012; Macknick et al., 2015).

ReEDS data contains both power generation by balancing authority and power inflows and outflow between balancing areas over sub-annual time periods. Balancing authorities are areas larger than counties. To harmonize with the FEWSION Database™ and disaggregate ReEDS data from the balancing authority to the county-level, the model's production numbers are disaggregated proportionally using the heat content of fuel consumption for electricity for each county's power plants (Energy Information Administration, 2017) and electricity demand is disaggregated proportionally by population.

In addition to error introduced in disaggregation, power wheeling within balancing regions is a significant portion of power flow, and this is another source of error (Bialek, 1996a; Bialek, 1996b; Bialek and Kattuman, 2004). To help compensate for the effect of wheeling on the water footprint of electricity, the water intensity of a power outflows from each balancing area was taken as the source-weighted average of the water intensity of power generation and power inflows. Therefore, virtual water outflows from a county in this database is the virtual water outflow associated with wheeled power through a balancing area (including power originating from this area's generation) in addition to virtual water outflows associated with power generation within that county.

Water Footprint of a Geographic Area

The water footprint of a geographic area (F_{Total}) is the sum of the direct water use (WU), virtual water inflows (VW_{In}), and virtual water outflows (VW_{Out}) (Hoekstra et al., 2012). For example, in the FEWSION Database™ v.1.0, the water footprint of withdrawals of a geographic area for all economic sectors is $F_w = WU_w + VW_{In,W} - VW_{Out,W}$ or alternatively $F_{Total} = WU_W + VW_{Net,W}$, where $VW_{Net,W} = VW_{In,W} - VW_{Out,W}$. The per-capita footprint is *F*` and is calculated by dividing *F* by the population of the county. Within the FEWSION Database™, the sum of *F* across all domestic trade in the U.S. yields $VW_{In,W} = VW_{Out,W}$ to ensure the water balance is conserved. *F* and each of its components are reported for each economic sector within each county in the U.S. in the FEWSION Database™. The derivation of $VW_{In,W}$ and $VW_{Out,W}$ are shown in section "Assigning Water Footprints and Virtual Water Flows using Trade Flows" in this document.

Surface Water Flow Methods

The FEWSION Database™ v. 1.0 contains a data layer that summarizes the county-to-county and state-to-state flows of surface water in the United States built from a fully linked river network from a county- or state-of-interest to the headwaters. In other words, this data layer summarizes the natural flow of rivers in the United States based on the political boundaries of county/county equivalents and states.

Full documentation of this method is located in Appendix A: Naturalized Water Flows.

Analytic Metric Methods

Each of the Analytics described below are calculated at both the state- and county-level in the FEWSION Database™ v. 1.0. Therefore, Analytics can be used to compare counties to other counties and states to other states in addition to exploring county-level and state-level differences for a single state.

Dependence

The Dependence metric is a different way of looking at the flow of goods into an area. Instead of measuring flow between an origin and destination in a physical unit like tons, dollars, barrels of oil, of GWh, the Dependence metric is a relative measure of how large a supplier is in a supply chain as a percent from 0 -100%. For example, a State purchases 100,000 gallons of gasoline from another state and consumes 200,000 gallons of gasoline overall. Using the Dependence metric, the State depends on the other state for 50% of its gasoline supply.

Leverage

The Leverage metric is a different way of looking at the flow of goods out of an area. Instead of measuring flow between an origin and destination in a physical unit like tons, dollars, barrels of oil, of GWh, the Leverage metric is a relative measure of how large a supplier is in a supply chain as a percent from 0 -100%. For example, a State sells 100,000 gallons of gasoline to another state and sells 500,000 gallons of gasoline overall. Using the Leverage metric, the state consuming gasoline has leverage over 20% of the producing state's its gasoline supply.

Circularity

The Circularity metric is a specific way of looking at the Dependence data layer for a specific physical unit like tons, dollars, barrels of oil, or GWh, among others. Rather than looking at all of the areas a state or county/county equivalent may depend on, the Circularity metric shows how much a state or county/county equivalent depends on itself. For example, a State purchases 100,000 gallons of gasoline from itself and consumes 200,000 gallons of gasoline overall. Using the Circularity metric, the State's circularity fraction is 0.5.

Resilience

The Resilience Analytic contained the FEWSION Database™ v. 1.0 is adapted from a previously published paper by the authors (Rushforth and Ruddell, 2016). The Resilience Analytic methods described in this section have been adapted from that paper.

Resilience is a measure of the potential for disruptions in a commodity supply chain. The potential for disruption is estimated by determining if a supply chain is overly reliant on a handful of sources, rather than relying on a diverse set of sources. Resilience is measured from 0 to 1. A score of 0 indicates that a supply chain is heavily reliant on one supplier, and if that supplier is disrupted, it may cause disruptions in supply. A score of 1 indicates that a supply chain relies on a diverse set of suppliers equally.

To estimate resilience, we constructed a Shannon Diversity Index based on each commodity flows dependence and leverage files. A normalized Shannon Diversity Index (SI^r) for each dependence and leverage file was computed on the discrete probability distribution *p* of for each SCTG+ Unit, *i*, or a coarser subsector or sector *i,* as,

(10) $$SI^r = \frac{-\sum_i p(V_{IN}(i)) \cdot \log p(V_{IN}(i))}{\log N}.$$

Vulnerability

The Vulnerability Analytic contained in the FEWSION Database™ v. 1.0 is adapted from a previously published paper by the authors (Rushforth and Ruddell, 2016). The Vulnerability Analytic methods described in this section have been adapted from that paper.

In the FEWSION Database™ v. 1.0, vulnerability is a measure of exposure to drought in a supply chain. Vulnerability is measured from 0 to 1. A score of 1 indicates that a supply chain is heavily reliant suppliers with stressed water supplies. A score of 0 indicates that a supply chain is not heavily reliant suppliers with stressed water supplies. Vulnerability can be visualized as a total for each area (IWSI) and compared to other areas or visualized to show the most vulnerable sources for a single area (IWSIc).

An Indirect Water Stress Index (*IWSI*) was developed to estimate the vulnerability of Flagstaff's hydro-economic network to large scale drought or water supply disruptions based upon a previously published Water Stress Index (*WSI*) for U.S. counties (Tidwell et al., 2011) combined with virtual water flows. Water stress is analyzed at the county-level (*k*) with respect to the annual allocated fraction of sustainably available surface fresh water resources. The *WSI* ranges from 0 to 1, where $WSI = 1$ indicates total allocation of a county's water resources and, consequently, little capacity to withstand hydrologic shocks, *e.g.* severe drought, which would cause water demands to exceed water availability. The county-level indirect vulnerability to a trading partner's water stress ($IWSI_{k\rightarrow F}$) is calculated as a trading partner's fractional contribution to Flagstaff's indirect vulnerability.

(11) $$IWSI_k = \frac{V_{k\rightarrow F}}{\sum_{all\ k} V_{k\rightarrow F}} \times WSI_k$$

The *WSI* employed here does not consider artificial augmentation of surface water supplies by transfers across county lines, and only accounts for the long-term average surface water stress not seasonal stress. This is an appropriate choice because local renewable surface water is the only sustainable water source over the long term, and because conveyed water resources are subject to many additional political and technological problems and will generally be under greater stress during times of drought. Still, this assumption means we have overstated vulnerability to short-term drought to the extent that a county is the holder of senior water rights and the recipient of water transfers from other locations.

Flow Metrics

There are two sets of metrics to measure and rank the total amount of a commodity flowing into or out of a geographic region. The first flow metric is the Total metric. The Total metric is the sum of commodity flows for specific a commodity into or out of a geographic area for a specific unit. Therefore, Total Inflows is the total amount of a commodity flowing into a geographic region for a specific unit, and Total Outflows is the total amount of a commodity flowing out of that geographic area for a specific unit for a specific unit for a specific unit. The second flow metric is the Rank metric. The Rank metric is the numeric rank of inflows (Inflow Rank) or outflows (Outflow Rank) into a geographic area for a specific commodity and unit. While the Total metric can return a large value, the Rank metric provides context for that number and shows how a geographic area compares to all others.

The FEWSION Database™ v. 1.0 Workflow

The processing steps to create the FEWSION Database™ v. 1.0 is comprised of several unique algorithms that ingest, manipulate, analyze, and extract new, novel, unique and useful information from publicly-available datasets describing the production, consumption, and flow of food, energy, and water in the United States between an origin and destination, including foreign-based imports and exports.

In general, the FEWSION workflow achieves the overarching goal described above through the following steps:

1. ingesting publicly-available commodity and electricity flow datasets;
2. extracting and classifying new commodity flows from the publicly-available commodity flow datasets;
3. statistically downscaling commodity flows to the county-level geographic scale and sub-county geographic scale at both the point of production and consumption using a variety of publicly-available datasets that describe the production and consumption of food, energy, electricity, water, and industrial commodities;
4. downscaling global commodity flows from foreign regions to individual counties using publicly-available foreign trade datasets;
5. assigning production and consumption to economic sectors, including storage, at the 3-to-6 digit North American Industrial Classification System (NAICS) code level;
6. embedding environmental attributes into the statistically-downscaled commodity flows;
7. routing commodity flows from origin-to-destination using publicly-available infrastructure network data to show how a flow of food, energy, electricity, water, and industrial commodities get from origin to destination;
8. and calculating trade analytics on the production and consumption of food, energy, electricity, water, and industrial commodities.

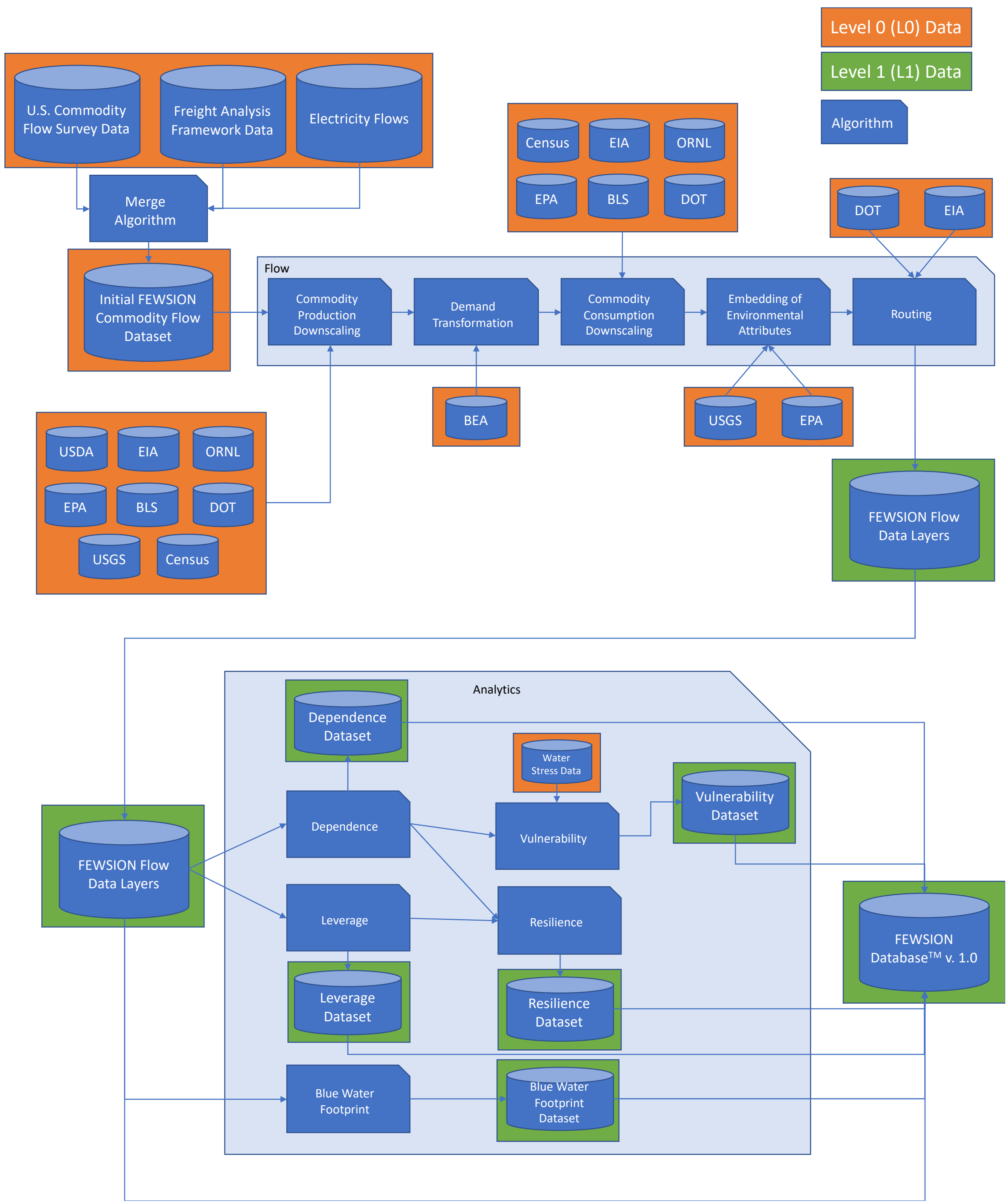
Data Levels

The FEWSION Project has adopted a modified NASA Data Processing Level schema (NASA, 2019. URL: https://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products)

Currently, the FEWSION Project's Data Processing Levels are:

- Level 0 (L0): Raw commodity flow data and input data in its native resolution and controlled vocabulary.
- Level 1 (L1): L0 data that is transformed/crosswalked into the FEWSION CV's; this may be straightforward or impossible depending on the case and may yield high-quality or low-quality data as the case may be.
- Level 2 (L2): L1 data that has QA/QC Flags applied to warn users about which values are reliable vs not (least publishable level).
- Level 3 (L3): Massaged L2 data, usually applying statistics or gap filling to fix the worst QC problems flagged in L2.

Figure 2: Flow Chart of the workflow behind the FEWSION Database™ v.1.0.



FEWSION Database™ v. 1.0 Extracts – File Formats and Names

Currently, all FEWSION Database™ v. 1.0 extract files are stored in .csv format. Data that have been formatted for the FEW-View™ visual interface are stored in a postgres database, but this documentation will not cover the FEW-View™ raw data file format or file naming convention.

FEWSION Database™ v. 1.0 extract files follow a general naming convention. The general naming convention is:

- 'FEWSION_+ <Version> + '_' + <Data Layer Type> + '_' + <Commodity Name> + '_' + <Unit> + '.csv'

Therefore, a FEWSION Database™ v. 1.0 extract file for the flow of Cereal Grains in tons would be:

- 'FEWSION_1_0_0_0_Flow_CerealGrains_tonnes.csv'

It should be noted that as the FEWSION data version is updated the version number will be updated. Also, the data layers are Flow, Dependence, Leverage, Circularity, Resilience, Vulnerability and Blue Water Footprint. Commodity names for the file names are located in Table 5. Unit names are for the file names are located in Table 6. All variables – version, data layer type, commodity name, unit – are built into the file names without spaces and underscores are used to separate variable names.

Variable Names/Column Headers for FEWSION Data Files

Table 7 contains variable names in FEWSION Database™ v. 1.0 extract files and their descriptions.

Table 7: FEWSION v. 1.0 Data Files Variable Names and Description

Variable Names	Variable Type	Description
Origin	string	No unit. Geographic code for the origin of a commodity flow. Code contains information about, country, state, metropolitan area and county of origin.
ProducerOrigin	string	NAICS Code
Destination	string	No unit. Geographic code for the destination of a commodity flow. Code contains information about, country, state, metropolitan area and county of destination.
ProducerDestination	string	NAICS Code, Population
Year	integer	Any year between 1960 and 2016. Currently only flows for 2012 in the database.
Quarter	string	1, 2, 3, 4 or A. Indicates the quarter within a year (1, 2, 3, 4) or the entire year (A).
Commodity	integer	FEWSION Commodity Code or SCTG2 Commodity Code.
SupplyChain	categorical	Code designation for what parts of the Supply Chain the origin is in and what parts of the supply chain the destination is in.
Mode	string	Three-digit transit mode code. The first digit is for an import flow, middle digit for a domestic flow, and the third digit is for an export flow. Domestic flows have only a non-zero digit in the middle. An import or export flow will have a domestic mode. No imports are exported and vice version, so the code will never have three non-zero digits.
Unit	categorical	Unit to measure the commodity flow [dollar, tonne, MW, GWh, barrel, mcf, virtual water consumption, virtual water consumption (Mm3), virtual water withdrawal (Mm3), Mm3] or analytic description of flow [% of total, circularity percent, direct vulnerability index, indirect vulnerability index, resilience]
Measure	float	float number >0. Never negative.

Metadata Standards and File Names

The FEWSION Project uses the Ecological Metadata Language (EML) for generating metadata (Michener et al., 1997). Please see the Knowledge Network for Biocomplexity website for more about EML: https://knb.ecoinformatics.org/external//emlparser/docs/index.html.

EML is used because of its compatibility with other types of metadata, including:

> "Dublin Core Metadata Initiative, the Content Standard for Digital Geospatial Metadata (CSDGM from the U.S. Geological Survey's Federal Geographic Data Committee (FGDC)), the Biological Profile of the CSDGM (from the National Biological Information Infrastructure), the International Standards Organization's Geographic Information Standard (ISO 19115), the ISO 8601 Date and Time Standard, the OpenGIS Consortium's Geography Markup Language (GML), the Scientific, Technical, and Medical Markup Language (STMML), and the Extensible Scientific Interchange Language (XSIL)."
>
> Source: The Knowledge Network for Biocomplexity, URL: https://knb.ecoinformatics.org/external//emlparser/docs/eml-2.1.1/index.html

EML metadata files are generated in XML format using the EML Assembly Line (EML Assembly Line, URL: https://github.com/EDIorg/EMLassemblyline).

Example FEWSION Database™ v. 1.0 metadata is located in Appendix B: Example FEWSION Metadata in the Ecological Metadata Language (EML).

How to Access FEWSION Database™ v. 1.0 Data Extracts

Currently, there is no public-facing data repository for FEWSION Database™ v. 1.0 extract files, but one is planned for the near future.. Please contact the authors of "The FEWSION Database™ Version 1.0: Dataset Documentation and Guide" for full access to the FEWSION Database™ v. 1.0

Changes and Known Issues

Changes Between NWED v 1.1 and the FEWSION Database™ v. 1.0

There have been numerous changes between the publishing of Rushforth and Ruddell (2018), which is the publication of record for NWED v1 .1, and the release of the FEWSION Database™ v.1.0. There are 10 major changes between the two databases.

1. NWED v. 1.1 utilizes FAF version 3.5 while the FEWSION Database™ v.1.0 utilizes FAF version 4.4. FAF version 4.4. has new and regrouped FAF zones (notably, 132 FAF zones instead of 123 FAF zones) and updated flows based on updated input data. As a result of the new/modified FAF zones, the disaggregation factors (demand side and production side) for FEWSION 1.0 had to be updated. Unless noted below, FEWSION 1.0 utilizes the data cited in the HESS paper (NWED 1.1) as disaggregation factors.
2. NWED v. 1.1 contains 4 virtual water ranges: withdrawal, max consumptive use, median consumptive use, minimum consumptive use. The FEWSION Database™ v.1.0 only has withdrawal and median consumptive use statistics.
3. NWED v. 1.1 did not separate natural gas from commodity 19 (SCTG 19). The FEWSION Database™ v.1.0 estimates natural gas flows using flows of commodity 19 over pipeline (mode 6). Flows of commodity 19 not over pipeline remain as commodity 19 and flows of commodity 19 via pipeline are renamed natural gas.
4. The FEWSION Database™ v.1.0 utilizes new disaggregation factors for oil and natural gas updates. Both oil and Natural Gas utilize USDA ERS AND DHS data for production-side disaggregation instead of employment-based disaggregation. As noted above, natural gas was not NWED v. 1.1. Additionally, the oil layer utilizes DHS refinery data for demand-side disaggregation. Finally, the natural Gas uses a regression method on population, natural gas energy generation facilities, and industrial facilities for demand-side disaggregation.
5. The FEWSION Database™ v.1.0 has a refined power flow layer. The major refinements focused on updated geographic location data for power plants in Texas and the Mid-Atlantic region. A handful of power plants were omitted because of an inconsistency in source geographic information data which put the power plants in the ocean instead of within a county.
6. Additional units were added to the energy sector layers in the FEWSION Database™ v.1.0. The units include common units for energy type (barrels, MW, GWh, cubic feet, etc.) where NWED v. 1.1 had energy sector data in thousand tons, which is the native unit of the FAF data.
7. The FEWSION Database™ v.1.0 includes a naturalized water flow data layer produced by Dr. Tara J. Troy of the University of Victoria (Troy, T.J., 2019).
8. NWED v. 1.1 only contains flow data whereas the FEWSION Database™ v.1.0 included Analytics for all units (Table 6) in addition to Flow data. These Analytics are as follows.
9. The FEWSION Database™ v.1.0 includes roll up layers to group similar commodities. The roll up layers all contain origin->destination flow layers + the analytics layers.
10. The FEWSION Database™ v.1.0 aggregates all county-level Flow data into state-level data layers and then calculates Analytics on all state-level Flow data layers.

Known issues with the FEWSION Database™ v.1.0

Below is a list of known issues in the FEWSION Database™ v.1.0.

Home Bias in Consumption

Many commodity flow datasets suffer from a "home bias in consumption" effect where borders tend to have a stronger effect in shaping and impeding consumption than we would expect from other observed data. In the FEWSION Database™ v. 1.0, the home bias in consumption effect over-emphasizes consumption in port cities. One potential reason for this is that these datasets mix manufacturing flows and wholesale distribution flows into one 'commodity flow' (Hillberry and Hummels 2003). There methods to reduce the home bias effect. One is by removing wholesale distribution flows from the trade dataset. Future versions of the FEWSION Database™ will work to address this issue.

Data Levels

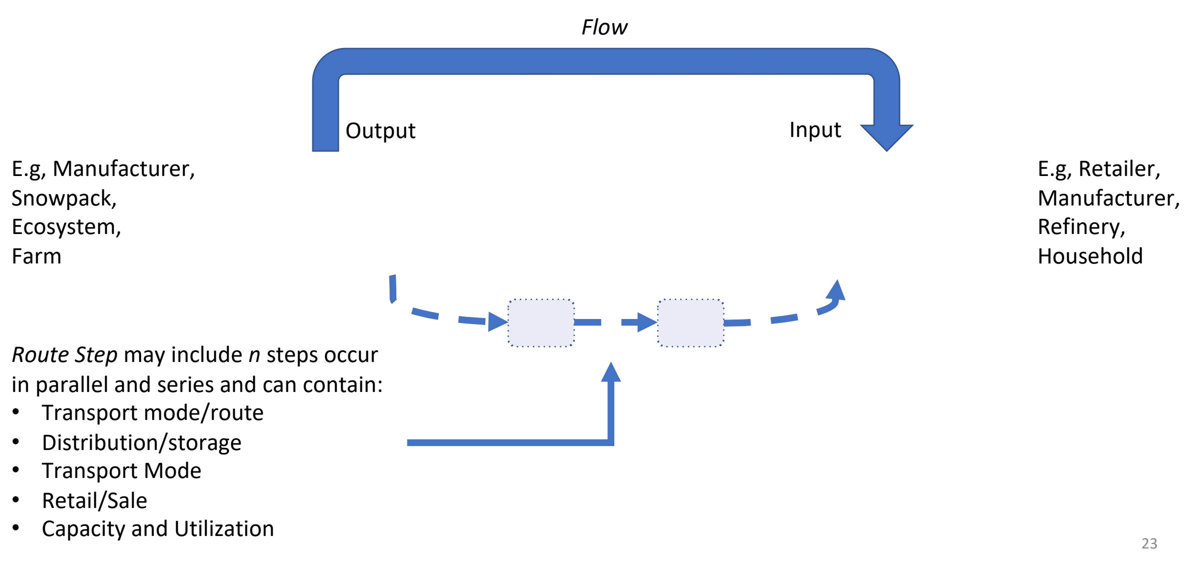
Currently, the FEWSION Database™ v. 1.0 only contains L1 Data. Future versions of the FEWSION Database™ will contain L2 and L3 data.

Routing

Currently, the FEWSION Database™ v. 1.0 does not contain any routing data.

However, the routing step has been presented in the FEWSION Database™ v. 1.0 Workflow section of this data documentation guide as a future placeholder (Figure 3).

Figure 3: Generic Routing Schema for future FEWSION Database™ versions.



Global Regions

Currently, the FEWSION Database™ v. 1.0 only contains information and import/export flows to the U.S. in relation to large global regions. Future versions of the FEWSION Database™ will address this known issue.

Glossary

To follow is a glossary of relevant terms for the FEWSION Database™ v.1.0 adapted from Rushforth and Ruddell (2018).

Agricultural Sector: Economic sector comprised of farm-based activities to grow crops for food or industrial purposes. Irrigation is the primary water using activity in the agricultural sector (Maupin et al., 2014).

Attraction Factor: A fraction used to disaggregate commodity flows on the consumption side. In the FEWSION Database™ v.1.0, population is used as an attraction factor. Each county within a FAF zone is assigned a fraction equivalent to its percent of the total population.

Circularity: The Circularity metric is a specific way of looking at the Dependence data layer for a specific physical unit like tons, dollars, barrels of oil, or GWh, among others. Rather than looking at all of the areas a state or county/county equivalent may depend on, the Circularity metric shows how much a state or county/county equivalent depends on itself. For example, a State purchases 100,000 gallons of gasoline from itself and consumes 200,000 gallons of gasoline overall. Using the Circularity metric, the State's circularity fraction is 0.5.

County: A county or county equivalent (parish, borough, Washington D.C., or an independent city) is a sub-state geographic scale that is roughly equivalent to the mesoscale.

Dependence: The Dependence metric is a different way of looking at the flow of goods into an area. Instead of measuring flow between an origin and destination in a physical unit like tons, dollars, barrels of oil, of GWh, the Dependence metric is a relative measure of how large a supplier is in a supply chain as a percent from 0 -100%. For example, a State purchases 100,000 gallons of gasoline from another state and consumes 200,000 gallons of gasoline overall. Using the Dependence metric, the State depends on the other state for 50% of its gasoline supply.

Destination: The geographic location where a commodity flow terminates.

Freight Analysis Zone (FAF Zone): A group of counties that represents a metropolitan statistical area, census statistical area, or the remainder of the state (Southworth et al., 2010; Hwang et al., 2016)

Industrial Sector: Economic sector that produces industrial goods. Water use in the industrial sector includes, "fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility," (Maupin et al., 2014).

Inflow Rank: The numeric rank of how much of a specific commodity flows into a geographic area (county, state, metropolitan area) compared to all other geographic areas of that type for a specific unit.

Leverage: The Leverage metric is a different way of looking at the flow of goods out of an area. Instead of measuring flow between an origin and destination in a physical unit like tons, dollars, barrels of oil, of GWh, the Leverage metric is a relative measure of how large a supplier is in a supply chain as a percent from 0 -100%. For example, a State sells 100,000 gallons of gasoline to another state and sells 500,000 gallons of gasoline overall. Using the Leverage metric, the state consuming gasoline has leverage over 20% the producing state's its gasoline supply.

Livestock Sector: Economic sector comprised of the raising of animals for animal products in addition to aquaculture activities. Water use in the livestock sector only includes direct water use at livestock, and related facilities (Maupin et al., 2014).

Mining Sector: Economic sector comprised of mineral producing activities, including metallic and non-metallic ore, in addition to sand and gravel, crude petroleum and natural gas. Water using activities in the mining sector include, "Mining water use is water used for the extraction of minerals that may be in the form of solids, such as coal, iron, sand, and gravel; liquids, such as crude petroleum; and gases, such as natural gas," (Maupin et al., 2014).

Origin: The geographic location where a commodity flow originates.

Outflow Rank: The numeric rank of how much of a specific commodity flows out of a geographic area (county, state, metropolitan area) compared to all other geographic areas of that type for a specific unit.

Production Factor: A fraction used to disaggregate commodity flows on the production side. In the FEWSION Database™ v.1.0, multiple production factors are used specific to the economic sector. Each county within a FAF zone is assigned a fraction equivalent to its percent of the total population.

Power Sector: In the FEWSION Database™ v.1.0, the power sector is comprised of electric generating stations, which includes thermoelectric and non-thermoelectric facilities (renewable energy sources). Water is used at thermoelectric generation stations in addition to hydroelectric facilities.

Resilience: Resilience is a measure of the potential for disruptions in a commodity supply chain. The potential for disruption is estimated by determining if a supply chain is overly reliant on a handful of sources, rather than relying on a diverse set of sources. Resilience is measured from 0 to 1. A score of 0 indicates that a supply chain is heavily reliant on one supplier, and if that supplier is disrupted, it may cause disruptions in supply. A score of 1 indicates that a supply chain relies on a diverse set of suppliers equally.

Total Inflows: The total amount of a specific commodity flowing into a geographic area (county, state, metropolitan area) for a specific unit.

Total Outflows: The total amount of a specific commodity flowing out of a geographic area (county, state, metropolitan area) for a specific unit.

Virtual Water: Also known as indirect water or embodied water, has been studied as a strategic resource for two decades as it allows geographic areas (country, state, province, city) to access more water than is physically available (Allan, 1998; Allan, 2003; Suweis et al., 2011; Dalin et al., 2012; Wang et al., 2015; Zhao et al., 2015; Marston et al., 2015).

Virtual Water Inflows into a Geographic Area (VW_{In}): The volume of water indirectly consumed to produce goods or services produced outside a geographic boundary of interest for consumption within that geographic boundary of interest.

Virtual Water Outflows from a Geographic Area (VW_{Out}): The volume of water used to produce goods or services that are consumed outside of the geographic boundary of interest.

Virtual Water Balance of a Geographic Area (VW_{Net}): Virtual water Inflows minus virtual water outflows for a geographic boundary of interest.

Water Footprint: The volume of surface water and groundwater consumed during the production of a good or service and is also called the virtual water content of a good or service (Mekonnen and Hoekstra, 2011a).

Water Footprint of Consumption: Water consumption for local use in addition to virtual water import (Mekonnen and Hoekstra, 2011b)

Water Footprint of a Geographic Area (F): The volume of water representing direct water consumption plus virtual water inflows minus virtual water outflows for a geographic boundary of interest. A per-capita water footprint (F`) is F divided by the population within the geographic boundary of interest.

Water Footprint of Production: the total volume of water consumed with a geographic boundary, including water consumption for local use less virtual water export (Mekonnen and Hoekstra, 2011b).

Water Consumption (C): The total volume of water consumed from a water source, when consumption is withdrawals minus return flows. A water source is either surface water or groundwater. The FEWSION Database™ v.1.0 utilizes four consumptive use scenarios based on a withdrawal-based scenario, and minimum, median, and maximum consumptive use scenario. Consumptive use scenarios are based on reports published by the United States Geological Survey (Shaffer and Runkle, 2007).

Vulnerability: In FEW-View, vulnerability is a measure of exposure to drought in a supply chain. Vulnerability is measured from 0 to 1. A score of 1 indicates that a supply chain is heavily reliant suppliers with stressed water supplies. A score of 0 indicates that a supply chain is not heavily reliant suppliers with stressed water supplies. Vulnerability can be visualized as a total for each area (IWSI) and compared to other areas or visualized to show the most vulnerable sources for a single area (IWSIc).

Water Withdrawal (W): The total volume of water withdrawn from a water source. A water source is either surface water or groundwater.

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Appendix A: Naturalized Water Flows

Dr. Tara J. Troy

The naturalized water flow layer contains river flows between counties, such that for any given county in the U.S., all the flows from upstream counties are quantified. This provides a picture of the dependency of a given county on locally generated surface water vs. upstream sources. The water flows are modeled to remove the influence of infrastructure, such as dams, and water use, such as water withdrawals for irrigation.

Natural runoff and baseflow

The runoff and baseflow generated by the land surface is modeled using the Variable Infiltration Capacity (VIC) model [*Liang et al.*, 1994; 1996], which is a physically-based land surface model that solves for water and energy budget closure. The calibration parameters are taken from [*Troy et al.*, 2008], and other inputs such as vegetation type and soil texture are from the NLDAS project [*Mitchell et al.*, 2004]. The meteorological data is daily precipitation, wind speed, and maximum and minimum temperature at 1/8° latitude by longitude resolution for 1949-2010 [*Maurer et al.*, 2002]. This water layer is one calendar year – 2010 – of streamflow to match with the other datasets used within the FEWSION data product.

Streamflow routing

In order to best preserve the river networks at the county scale, streamflow routing is performed at the 1km resolution throughout the contiguous United States (CONUS). This reduces errors introduced by using the county as the spatial unit of analysis for routing, as a county may contain multiple rivers that flow into multiple counties. For example, this could lead to a county being incorrectly identified as water stressed.

Flow direction is taken from HydroSHEDS [*Lehner et al.*, 2008] at the 1km resolution. To go from the 1/8° resolution of VIC to the 1km resolution, the VIC grids are uniformly downscaled to the 1km resolution. This means every 1km pixel within the larger VIC grid cell has the same runoff and baseflow. VIC generates depth of runoff and baseflow; this is converted to volume by multiplying by the area of each HydroSHEDS pixel.

To track water moving between counties, every county border crossing is identified. For each location where a river link crosses the county, the upstream 1km pixels within the county that drain to the location are identified. The flow from VIC is routed to each crossing using a simple lumped routing method. Then, all upstream crossings coming into a county are connected to their downstream crossings to the next county. This preserves the river network while tracking water flows between counties.

References

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Appendix B: Example FEWSION Metadata in the Ecological Metadata Language (EML)


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        <givenName>R</givenName>
        <surName>Rushforth</surName>
      </individualName>
      <organizationName>Northern Arizona University</organizationName>

<electronicMailAddress>richard.rushforth@nau.edu</electronicMailAddress>
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        <givenName>R</givenName>
        <surName>Rushforth</surName>
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  The FEWSION Database(TM) is a spatially and temporally detailed
  input-output database describing the food-energy-water (FEW) system in
  communities of the United States, along with other commodity flows,
  and their resource footprints and dependencies. In particular, FEWSION
  aims to estimate high-resolution FEW flows for the entire nation,
  including major import and export FEW flows. The goal of the FEWSION
  Project is to produce FEW data for researchers, decision-makers, and
  the public. This data documentation and guide is intended for use in
  conjunction with the FEWSION Database™. The information in this
  document describes the coverage, methods, processing techniques,
  statistical methods, schemas, source material, file structure, and
  file formats for the FEWSION™ Database. Integrating analysis of food,
  energy, and water (FEW) system models face numerous methodological and
  analytical challenges. Chief among these challenges are data quality,
  availability, comprehensiveness, and concordance. Data fusion – the
  curated combination of multiple disparate datasets to produce novel,
  synthetic datasets – is central to creating integrated FEW system
  models and datasets. However, these datasets often lack concordance
  with respect to one or multiple characteristics such as geographic
  scale, boundary definitions, classification schema, and/or
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  The preferred citation for this database is: Rushforth, R.R. and B.L.
  Ruddell (2019), The FEWSION Database(TM) Version 1.0: Dataset
  Documentation and Guide. FEWSION Project, https://fewsion.us/data. To
  cite a specific commodity data layer, the preferred citation is
  Rushforth, R.R. and B.L. Ruddell (2019), The FEWSION Database(TM)
  Version 1.0: Dataset Documentation and Guide. FEWSION Version
  <emphasis>Version #</emphasis> <emphasis>Data Layer Type</emphasis>
  Data Layer for <emphasis>Commodity Name</emphasis> and
  <emphasis>Unit</emphasis> units. FEWSION Project,
  https://fewsion.us/data.
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   Publicly accessible extracts from the FEWSION Database™ are licensed to the
   user under the Creative Commons License "Attribution-NonCommercial-
   ShareAlike 4.0 International (CC BY-NC-SA 4.0)", Accessible at
   https://creativecommons.org/licenses/by-nc-sa/4.0/legalcode. You must give
   appropriate credit, provide a link to the license, and indicate if changes
   were made. You may not use the material for commercial purposes. If you
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  remix, transform, or build upon the material, you must distribute your
  contributions under the same license as the original. The FEWSION Database™
  is the property of Northern Arizona University and the Arizona Board of
  Regents.
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  FEWSION 1.0 Methods can be found in the data documentation guide:
  Rushforth, R.R. and B.L. Ruddell (2019), The FEWSION Database(TM)
  Version 1.0: Dataset Documentation and Guide. FEWSION Project,
  https://fewsion.us/data. Additionally, data documentation on the
  database the immediately predated the FEWSION database can be found
  at: Rushforth, R. R., &amp; Ruddell, B. L. (2018). A spatially
  detailed and economically complete blue water footprint of the United
  States. Hydrology and Earth System Science. https://doi.
  org/10.5194/hess-2017-650.
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          <surName>Ruddell</surName>
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      </personnel>
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