Data Analysis of Global Impacts From Population Increases

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Abstract – The research conducted for this report focused on establishing clear visualizations on the impact of increasing populations and their impact on the environment. The initial theory of negative impacts on the environment from population increases was described in the book *The Limits to Growth* by Donella Meadows, Dennis Meadows, Jorgen Randers, and William Behrens in 1972. The team collected data representing the impacts introduced by the book and developed information visualization as described in the following document. The focus was to determine potential impacts of population increases by analyzing the data through visualizations. The evolution of research and thought trends were also explored.

1 Introduction

The influential 1972 book, “The Limits to Growth” (TLTG) predicted an emerging crisis between environmental resources and an ever-increasing global human population. However, it provided few concrete solutions for the problem it so cogently confronted. In order to assess the current state of ecological resources, the authors of this article collaborated to collect and visualize air quality and water scarcity data. Visualizations were also developed in relation to potential solutions and related thought trends that have subsequently emerged since the publication of TLTG.

During research, the concepts of system dynamics and circular economics bubbled up to the surface. In the early 1980’s, the System Dynamics Society was founded which included two authors of TLTG (Donella Meadows and Jorgen Randers). System dynamics can be described as “a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems — literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality” [1]. Judging from the participants as well as the description of this concept, it is clear that system dynamics evolved out of the question of limited resources and carrying capacity on planet Earth. The team aimed to visualize this connection.

Circular economics is a concept first developed by Kenneth Boulding in his 1966 book “*The Economics of the Coming Spaceship Earth.*” Boulding is widely recognized as the father of ecological economics. He described modern consumptive patterns as “cowboy economics” and advocated instead for a kind of “spaceship economics” that emphasizes recycling and renewal energy in place of rabid consumerism. Boulding may have been the first to compare economic systems to biological systems, where energy becomes the primary dynamic which influences the use of resources. This concept is tightly woven to thermodynamic systems in which entropy (the amount of energy not available) is evaluated in relation to closed systems. One of the visualizations presented in this paper will reflect this particular evolution of thought.

2 Visualization #1: Alluvial Thought Flows

2.1 Tools

An exploration of Jigsaw was initially employed to compare the summary texts on TLTG, the book “2052” by Jorgen Randers [2], and a report on Circular Economics from the Ellen MacArthur Foundation [3]. However, the visualizations failed to impress, so other tools were investigated.

The final visualization was created using CiteSpace in combination with Alluvial Generator to create an alluvial flow diagram that linked concepts from TLTG to citations of Kenneth Boulding’s works on circular economics. Citation files were created for each search, then imported into Citespace [4] and processed for keywords and burst terms. The terms were visualized within Citespace to get a sense of the robustness of the data. When it was determined to be satisfactory, the files were exported to Pajek format and imported as networks into Alluvial Generator for further exploration.

2.2 Methods

The Web of Science was used to extract citation records of TLTG and a second set of citations was created based on the works of Kenneth Boulding. Cited Reference Searches were conducted on the authors “Meadows DH” and “Boulding K” in the Web of Science Core Collection [5]. These citations lists were imported into Citespace and processed for burst terms then exported to Pajek format so that they could be imported into Alluvial Generator to create an alluvial flow diagram.

In Alluvial Generator, five key concept areas emerged: ecology/sustainability, economics, social concerns, energy and models. These areas were color coded to distinguish them in the visualization and the term-based network nodes were manually adjusted to move them either up and down the visualization columns in order to group similar terms more closely together. Some terms were left uncolored due to the general nature and marginal relevance to the subject matter. For example, the term “quality” was linked to “customer service” and was not relevant to the focus of this project, so a pale gray color was selected to allow this link to fade into the background.

2.3 Results

The results in Figure 2.1 show a strong link between TLTG and circular economics on environmental concepts (in green). Ecology and sustainability are interwoven between these research areas particularly in the areas of climate change, biodiversity and China. Strong links can also be detected between environmental economics (in orange) and almost all of the key concepts that are associated with circular economics. These connections appear as orange “trails of thought,” much like those anticipated by Vannevar Bush in his discussion “As We May Think” [6]. Also notable are the connections between pollution and “firm” (corporate bodies); peak oil’s linkage to thermodynamics and business; future research’s linkage to business, world and climate change; and the connection of innovation to organizational change.

Concepts of system dynamics are represented in the “model-building and “agent-based” nodes. These connections are shown in yellow. Agent-based analysis uses computer simulations to examine how a single autonomous agent interacts with its environment. It may also examine the collective behavior of these agents. This is certainly apropos to examining the interactions of human communities and their surrounding natural world.

Finally, in blue are links between socially focused concepts such as organizations, communities, businesses and other anthropocentric foci. It is interesting to note that many of these areas appear as large, disconnected blocks.

2.4 Interpretation

Overall, the resulting visualization links the thoughts of the “mother” of TLTG (Donella Meadows and team) to the “father” of circular economics, Kenneth Boulding. At the highest level, one is struck by the interconnected nature of the thought patterns, as well as the occasional isolation of concepts such as thermodynamics and business. It is as if we are looking at a research field in mid-stage of development, where interdisciplinary questions are still being explored and potential solutions are being actively developed. While some of the latter visualizations in this paper may expose a heightening crisis around air and water, the alluvial flow diagram shows that the connections are being made even if the solutions are not on the ground just yet.

It is perhaps not surprising that the strongest connections between the concepts from TLTG are tightly woven into the concepts of circular economics, as they represent concurrent issues that may have even been influenced by the earlier works of Rachel Carson, most notably her work “Silent Spring” [7] which exposed the lethality of DDT and other chemicals on birds and the wider natural world. It is a little disappointing that system dynamics has not made a wider contribution to the discussion of economic models as it may hold potential for balancing a strong economy with a healthy environment. A visualization such as this one might help provide valuable feedback to researchers and thinkers in the areas of both system dynamics and circular economics.

There also appears to be an imbalance between the emphases of social concepts in TLTG as compared to circular economics. This can be observed by the predominance of blue blocks on the right compared to relatively few on the left side of the diagram. Perhaps efforts around modeling best represent social research in TLTG column.

In terms of modeling, it is good to see the development of these research trends making connections to organizational change and further research, however the diagram also shows few linkages to practical social structures such as business and organizations. Bringing such models to bear in society appears to be an area worthy of further, perhaps urgent development.

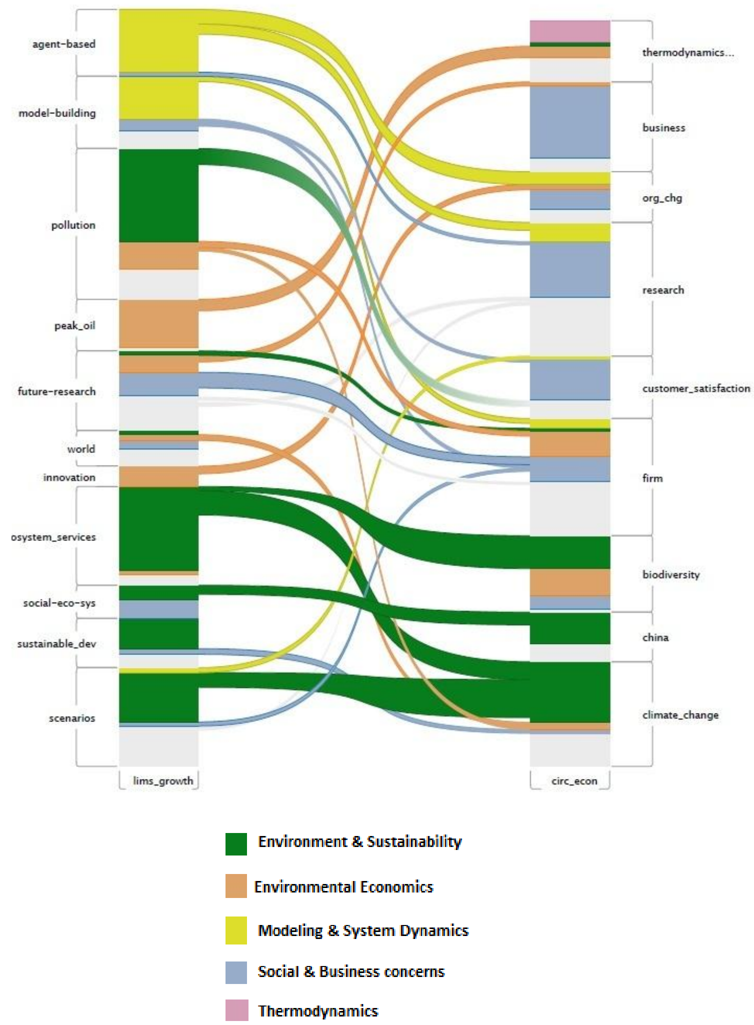

Figure 2.1 Alluvial Diagram

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Brazil

	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Agricultural water withdrawal *(10^9 m3/yr)*					33.43 *(1996)*	36.63L *(2000)*	31.7 *(2006)*	
Agricultural water withdrawal as % of total water withdrawal *(%)*					60.93 *(1996)*	61.77L *(2000)*	54.59 *(2006)*	
Total water withdrawal per capita *(m3/inhab/yr)*			247.1K *(1987)*		328.8K *(1996)*	330.8K *(2000)*	306K *(2006)*	

China

	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Agricultural water withdrawal *(10^9 m3/yr)*		391.2 *(1980)*	415.2I *(1985)*	415 *(1990)*	407.7 *(1993)*		358 *(2005)*	
Agricultural water withdrawal as % of total water withdrawal *(%)*		88.17 *(1980)*	86.3I *(1985)*	83 *(1990)*	77.6 *(1993)*		64.61 *(2005)*	
Total water withdrawal per capita *(m3/inhab/yr)*		428.9K *(1980)*	430.5K *(1985)*	415.9K *(1990)*	415K *(1993)*		409.9K *(2005)*	

India

	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Agricultural water withdrawal *(10^9 m3/yr)*	353.4 *(1975)*	411.7I *(1980)*	468I *(1986)*	460 *(1990)*		558.4L *(2000)*		688 *(2010)*
Agricultural water withdrawal as % of total water withdrawal *(%)*	93 *(1975)*	93.93I *(1980)*	94.09I *(1986)*	92 *(1990)*		91.48I *(2000)*		90.41 *(2010)*
Total water withdrawal per capita *(m3/inhab/yr)*	582.6K *(1975)*	597.8K *(1980)*	606.7K *(1986)*	549.4K *(1990)*		560.7K *(2000)*		604.8K *(2010)*

Pakistan

	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Agricultural water withdrawal *(10^9 m3/yr)*	150.3 *(1975)*			150.6 *(1991)*		162.7L *(2000)*		172.4 *(2008)*
Agricultural water withdrawal as % of total water withdrawal *(%)*	97.98 *(1975)*			96.79 *(1991)*		94.26L *(2000)*		93.95K *(2008)*
Total water withdrawal per capita *(m3/inhab/yr)*	2 104K *(1975)*			1 319K *(1991)*		1 148K *(2000)*		1 020K *(2008)*

United States of America

	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Agricultural water withdrawal *(10^9 m3/yr)*	106.5 *(1974)*	117.1 *(1979)*		194.7 *(1990)*	195.6I *(1995)*	196.5 *(2000)*	192.4 *(2005)*	
Agricultural water withdrawal as % of total water withdrawal *(%)*		22.62K *(1980)*		42.1 *(1990)*	41.79I *(1995)*	41.51 *(2000)*	40.22 *(2005)*	
Total water withdrawal per capita *(m3/inhab/yr)*		2 210E *(1980)*		1 791K *(1990)*	1 717K *(1995)*	1 641K *(2000)*	1 583K *(2005)*	

Figure 3.1 Agricultural water utilization among the world's largest producers

3 Visualization #2: Water

3.1 Tools

The choice for finding raw quantitative water data was AQUASTAT. It presented the information in a one-dimensional chart accompanied with legends which made it easy to read. The tools provided were sufficient enough to help arrive at a conclusion. We were able to generate statistical data related to water resources for countries around the world. AQUEDUCT is a web-based visualization tool that provided the information in a 3-D geographic format on the impact of water resources. We also used CitNetExplorer ('Citation Network Explorer') [27]. It is a software tool used to analyze and visualize citation networks of scientific publications. It will provide important articles, as well as reveal how often the topic has been discussed and how these articles influence each other.

3.2 Methods

The team wished to clarify a few things during research which included determining the current water resource conditions, how much has changed over the years, and how water consumption is being managed globally. The results on water consumption were clear (Figure 3.1): worldwide, agriculture accounts for 70%, industry usage accounts for 20% and domestic usage consumes 10% [8]. Given that there were enormous sets of data and a lack of aggregate tools available, we focused on countries which required the most water resources for agriculture since that accounted for the largest percentage (70% of global water usage). We also looked at water usage for industrial purposes, since the rate has remained very steady, whereas agriculture usage has been rising and this required further investigation.

AQUASTAT allowed us to narrow down the search. Users are able to search for information filtered by countries and variables spanning back to 1970s; however, the amount of available data tended to decline the further one researched into the past. One of the benefits of using AQUASTAT are the different levels of variables by which the information can be filtered. Examples include water resources: External, Internal, Renewable, Water Use, Area under Agricultural Water Usage, and so on.

AQUEDUCT's Water Risk tool had useful filters based on commodity crops, zooms and highlighted statistics. It also linked related reports to water resources which were very useful for research. The highlighted colors on the maps were intuitive: Low risk areas appear in yellow, high risk areas in red and Low Water use in gray. We explored options and the results are based on All Commodity Crops and used the Agricultural weighting scheme.

CitNetExplorer ('Citation Network Explorer') data is based on data from Web of Science [5]. The dataset in Figure 3.2 included Desalination, Water Shortage, Water Capacity, Water Renewal, and Water Resource. Through the visualization, we were able to find publications related to the subject. Circles or squares represent a publication with the author's name hovering over the objects. There are plenty of search features that fulfill the Schneiderman mantra of "zooms, filtering and overview" [17] as well as highlights in CitNetExplorer. The publications that have been cited the most are easily identifiable. The publications could be accessed with the right click of the mouse and this allowed us to conduct research very easily. There are also info boxes which show the number of publications and citation relationships in the network. Additional bibliographic information is shown when the mouse is hovered over publication nodes.

The evaluation was based on publications retrieved and the distance between the overlapping labels. Research focused on neighboring publications as they had the most relevance to the subject. We also drilled down to publications on the sub network with the most citation factors. Marked publications were displayed as squares instead of circles. Clustering of the networks also provided insights on publications that were closely connected to each other. At one point, the water resource data set provided too many records so it was filtered it by looking at the core publications with a minimum of four citations.

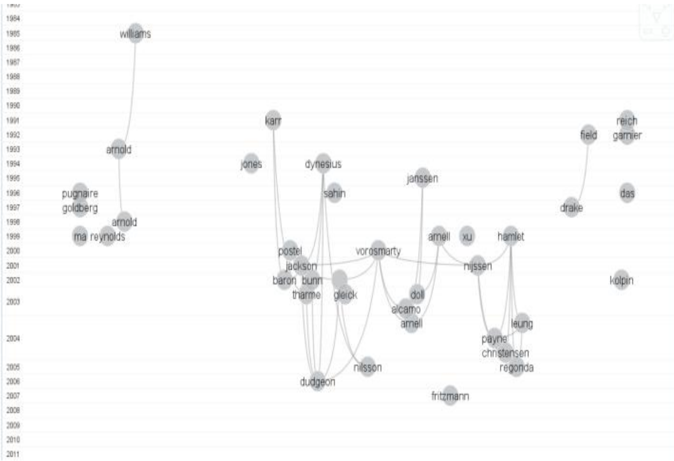

Figure 3.2 – CitNetExplorer – citation network showing cited publications (Water resource Dataset)

3.3 Results

Water Consumption

There is evidence that there are water shortage risks across the world. Hotter regions such as India, sections of the US and vicinities near deserts seem to be suffering the most. This could become an issue since the United States and India are the two top agriculture producers in the world (rice, wheat, corn, etc.). [9] At a quick glance, there's indication that water usage has been steadily rising within the past 40 years. Presently, 56% of irrigated agriculture is facing high water stress levels. AQUEDUCT [23] highlights these regions of concern in Fig 3.3.

There has been a combination of factors which illicit the shortage of water in some countries as compared to others. It appears that we are starting to reach capacity and some areas are being affected more than others with greater frequency [24, 25, 26].

Water Renewal

An analysis was performed on water renewal trends since the 1970s and according to AQUASTAT it has been consistent. However, with newer technology such as desalination methods, even greater water renewal rates were anticipated. It appears that costs have been a major attribute to the lack of such water restoration methods.

There has been evidence that for some countries, water renewal rates will not be sufficient enough to sustain normal life and alternative water replenishment systems are becoming mandatory. Unfortunately countries who are less fortunate will continue to suffer. [10] Citation tools indicate that water renewal is required in the future since more water is becoming unusable due to pollution. [10]

Water resources are also threatened by the industrial world which accounts for 20% of global water usage. Industry is also responsible for alarming rates of water use. Common culprits include hydroelectric dams, power plants and oil refineries, which use water in chemical processes, and manufacturing plants, which use water as a solvent. Through CitNetExplorer, there were several articles detailing problems in countries such as China and India and the efforts they are undertaking to resolve the issues [11]. Publications with higher citation scores were related to research that explored that state of water resources in the world today.

3.4 Interpretation

The team was able to gather a lot of information with the selected tools. It was evident that agriculture accounted for the majority water usage in the world. By looking at the geographic maps generated, some countries may be at high risk of water shortages due to their location near the equator and a lack of replenishing systems. AQUASTAT indicated a definite rise in the use of water and that water renewal rates are not keeping up with utilization rates and economic growth. It may be inferred that this will become an issue in the long run. Through CitNetExplorer and articles linked

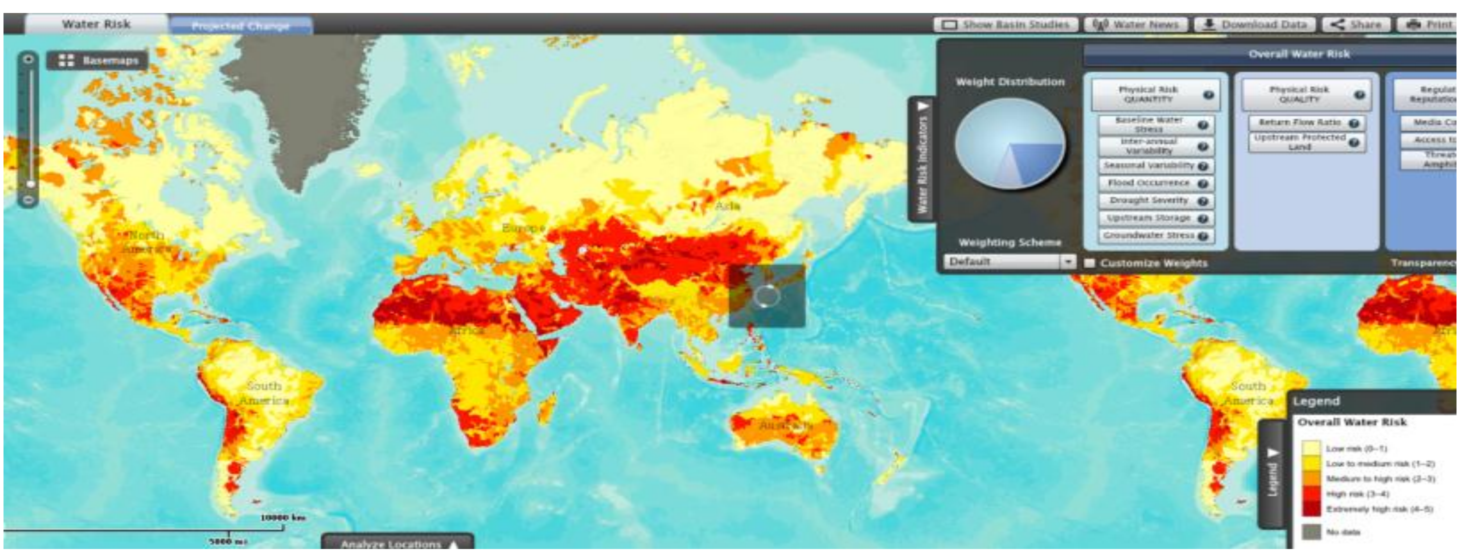

Figure 3.3 – AQUEDUCT Water risk tools, highlighting the level of risk in water scarcity.

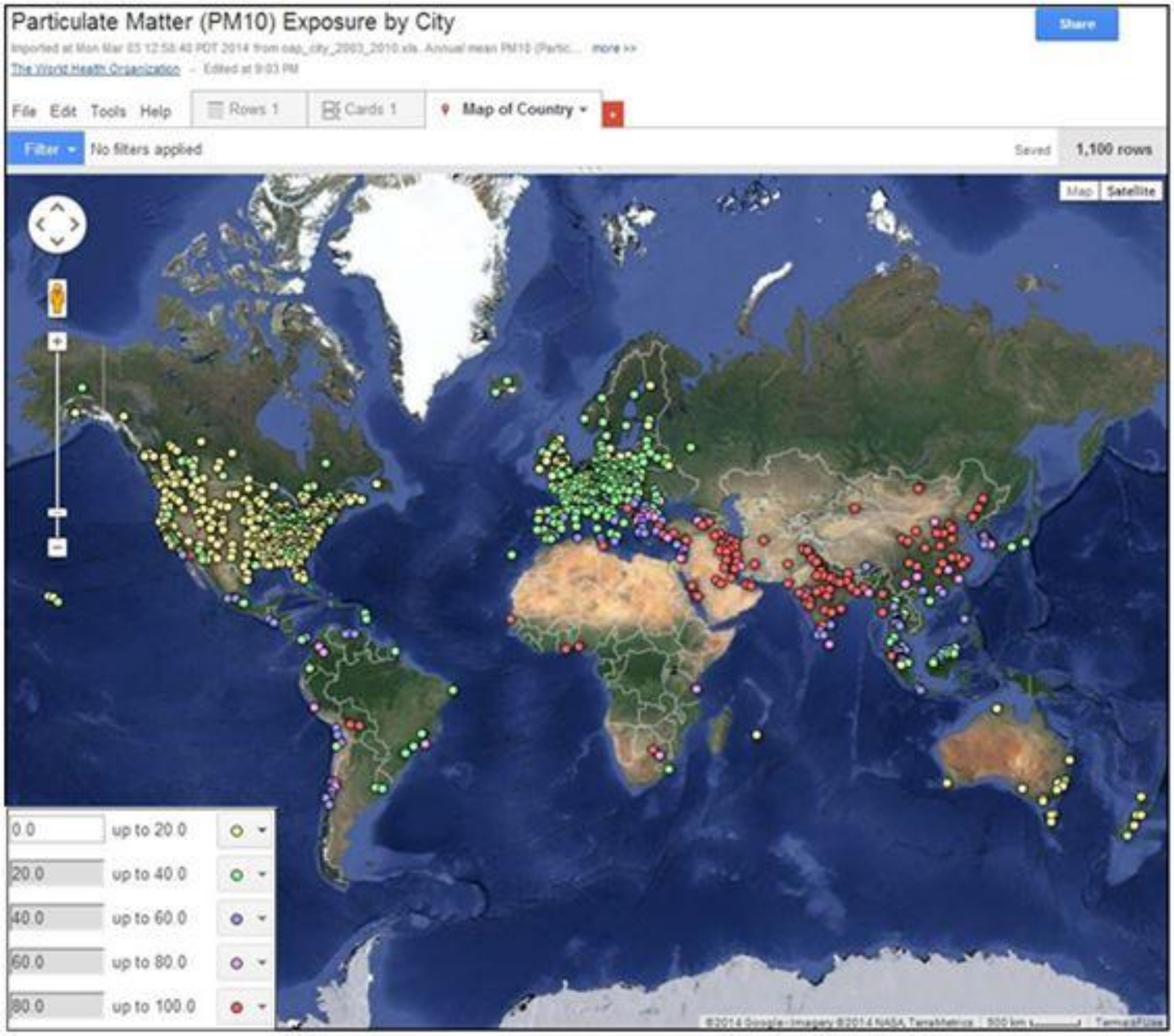

Figure 4.1 Global Air Quality Indicators

through AQUEDUCT, it was clear that parts of the world are starting to suffer from a lack of fresh water and some are taking action because doing nothing is no longer an option. Based on these findings, it is clear to us that the world is starting to reach peak water capacity. There are factors that influence the supply (population usage, pollution, changing climates, etc.) and some countries are hit harder than others. If we can better manage existing water supplies and build replenishing systems, we may be able to defer water shortages. However, life on earth is in constant change and nothing is ever certain, however, with the aid of information visualizations we may be able to find better methods to sustain life-giving water on Earth.

4 Visualization #3: Global Air Quality

4.1 Tools

For the purpose of illustrating the decline of air quality on a global scale decided to use Google's Fusion Tables [12]. This application provides the ability to upload the raw data in the form of CSV, TXT, XLS or KLM and display it in a format that conveys the quality of air samples found in cities around the world. Google's Fusion Tables has the capability to create and associate specific ranges with colors according to their respective results. The interactive, online application further enhances the user's experience by providing zoom and filter options to better analyze the data sample.

4.2 Methods

In an effort to provide an illustration of air quality from cities around the world a centralized and credible source was needed to provide the data. The air quality research was provided by the World Health Organization's (WHO) website (http://www.who.int). The focus was to establish credible data samples from cities located in different regions around the world. Beginning in 2003 through 2010, WHO has collected samples from reliable and credible locations and individuals.

The goal for using the WHO data in association with Google's Fusion Tables was to provide a visualization of air quality in regions where population growth has and is continuing to expand.

The raw data provided by WHO needed to be cleaned from any irrelevant rows/columns/worksheets that would not be needed for representation (i.e. title columns, symbols of measurements, etc.). Once the data file had been properly formatted it could then be uploaded to Fusion Tables.

By uploading the 'oap_city_2003_2010.xls' file provided by WHO into Fusion Tables, the application provides an analysis by country as a default. This was due to the data file coding the column for country data as the only column associated with the 'location' association. In order to provide representation for cities, the city column needed to be changed from 'text' to 'location.' This was available in the Change Columns section under the 'Rows1' tab. Once changed the application then performed geocoding to correctly identify locations and place markers at each representation. However, all markers were of the same color and needed to be individually color coded according to their Annual Mean PM10 measurement using the Buckets option in the features section for the map. At this point, the data was successfully represented and illustrated cities around the world with clean or poor air qualities.

4.3 Results

The data representation in the illustration provides a window into the air quality from samples taken from around the world. The unit of measurement is the annual mean of Particulate Matter (PM10) as measured in micrograms (ug) per cubic meter (m3). The Environmental Protection Agency (EPA) classifies PM10 as "particles with a diameter of 10 micrometers or less" [13]. According to the EPA, "major concerns for human health from exposure to PM-10 include: effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children, and people with chronic lung disease, influenza, or asthma, are especially sensitive to the effects of particulate matter. Acidic PM-10 can also damage human-made materials and is a major cause of reduced visibility in many parts of the U.S." [13]

The data representation in the visual above indicates samples measured as a daily concentration over the seven year timeline. The legend indicates that cities coded as yellow are in the lower acceptable range for air quality, whereas the red cities are considered very poor air quality locations. It's important to note that many countries have yet to collect data samples due to the lack of technological tools that are available to them. Additionally, Arctic and Antarctic regions have no reported collection samples in this set of data.

4.4 Interpretation

The data samples provided by the WHO between the years 2003 and 2010 provide an insight into the quality of air in cities from around the world. It's unclear from the visual in the preceding section that in populous region's air quality may not directly correspond to poor quality. Rather, countries may be focused on enforcing strict emissions standards to help reduce the amount of airborne particulate matter. For example, both the United States and central Europe show very low PM10 readings which are presumably due to strict emissions standards.

The visual representation of air quality does suggest that developing countries, such as India, may not have emissions standards in place to improve air quality. The visual representation clearly shows that India, and its surrounding regions, are among the worst regions for air quality with PM10 samples consistently above 100 ug/m3.

The ability to collect comprehensive air quality data samples throughout the world is still in its infancy stage. Many countries are just beginning to gain access to technological resources that will aid in the ability to collect and analyze air quality readings. As such, future data samples can be used in association with current samples to form a more collective data selection that can aid in better understandings of population impacts on air quality. The use of such samples can aid in and reinforce the value of emissions standard practices set forth by governments to help increase the quality of the air in their regions.

5 Visualization #4: ManyEyes Word Tree

5.1 Tools

The main tool used in this section was the ManyEyes word tree, which allows us to see how the words in a text are connected through a visualization of the possible word choices in the text after a given word. [14] The word tree can be manipulated so that actual phases from the book are formed. The relative sizes of the words in the visualization represent the frequency of that word in the text after the selected word. It is also possible to reverse the word tree to go backwards through the text. These features will allow us to find ideas in the text that are related to the other visualizations in this paper.

5.2 Methods

The dataset for this visualization is the text of "The Limits to Growth" by Donella Meadows, et al. (1972). We will demonstrate the importance of the ideas behind the other visualizations in this paper (from Brigitte Fortin, Greg Furman, and Thai Vong) relative to this book through the use of the word tree and terms provided by the other team members. This will show us how this book, which is a prediction of events up until the year 2070, relates to some current events. Additionally, a word cloud by Brigitte Fortin was consulted to quickly reference the most-used words in the text. Her co-citation analysis was utilized as well.

5.3 Results

The results are relayed in the visual presentations included as attachments with this paper, and discussed further in the following section.

5.4 Interpretation

Using the word tree to look up the main concepts helped form an idea of what topics and ideas might be contained in the book, and its main points and arguments. Looking up the main terms also helped to give an idea of the terminology that was used in the book. This is relevant as the book is from 1972, and many key terms associated with the modern environmental movement may not have been established at that time. This means that to relate the book to current ideas and events it is necessary to have some clue as to how those ideas would be worded at the time of publication.

Relating the book to the other visualizations could be hit-or-miss as the book describes some things more broadly, or uses different terms or descriptions than we would today. For instance, "climate change" did not appear in the book, although it did talk about reports that CO2 might trap heat inside the earth's atmosphere. Another example is the book's discussion of resources in a general sense, without much specific discussion on crucial particulars such as fresh water and oil.

Looking at the other visualizations more specifically, we can see how the ideas relate to the book.

Of the most direct relevance to the book is Brigitte Fortin's Citespace co-citation visualization. The terms that came out of this visualization are interesting in that they are not the most used terms in the book. They are terms that almost seem more related to a financial book as opposed to one about the environment, for example price and unit. As we can see from the results section presentation, these appear in the book in relation to reduced resources and an increasing demand for them. It is important to extend the phrases in the word tree to see in which sense the words are being used. For instance, "stock" in the book (with 15 hits) is used most often in the phrase "capital stock" (8 hits) which according to its dictionary meaning can be either the stocks issued by companies for trade, or an entity's use of resources in their industrial process. Extending the word tree in this case lets us know it is the latter, which may also throw some light on the co-citation clusters' meanings as well.

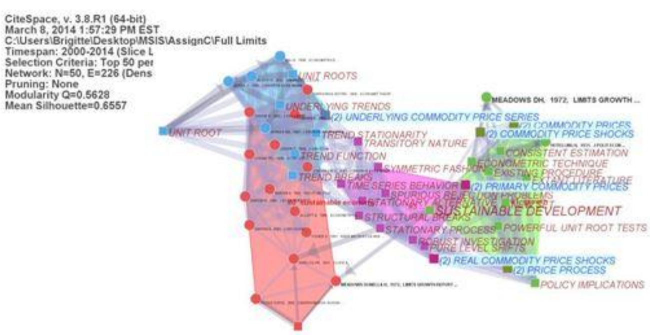

Figure 5.1 – Brigitte Fortin's co-citation analysis of "The Limits to Growth."

It is also interesting to note that some of the terms that appear in the clusters very rarely appear in the book, or even at all. This is true of the term "econometric technique" and "sustainable development" although ideas in the book, conceptually, do relate to these terms.

Thai Vong's visualization explores water availability issues. The key terms he identifies in his research are water consumption, water renewal, and water shortages. The word tree allows us to quickly determine that none of these phrases appear in the book by entering the word "water", although "water pollution" and "water runoff" are mentioned. This does not mean that Meadows et al were not concerned with this topic. Both "consumption" and "shortage*" have quite a few hits (34 and 10 respectively) but are mentioned in the context of resources in general or for other resources such as steel, chromium, and land.

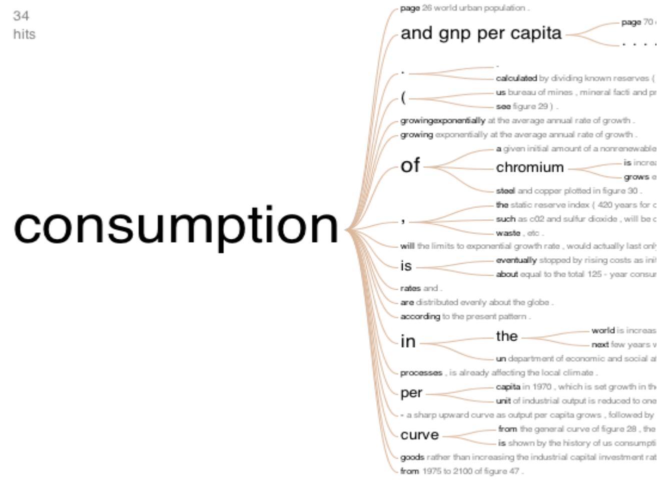

Figure 5.2 - The importance of the term "consumption."

There are also three or four passages that relate to the availability of water as an upper limit for development but once again they are in the context of a discussion about other resources, and often pollution is seen as the main limiting factor. There are just as many statements anticipating the invention or improvement of technologies that will increase the availability of water. Also, the terms "drought" and "precipitation" do not occur at all. This would make it seem that Meadows, et al did not anticipate how serious water shortage would be in the future, perhaps because the effects of climate change were not in the scientific lexicon at the time they formed their model, and because technologies aimed at increasing the water supply have not progressed to the degree described.

Greg Furman's visualization tackles the topic of air quality and pollution. Relevant terms for his visualization are "global air quality", "air pollution" and "particulate matter".

Particulate matter (PM) is one of the six criteria of air pollutants regulated by the Environmental Protection Agency (EPA). [15] It is well known to cause many problems in the human respiratory system, and if small enough can become lodged in the lungs and respiratory tract. While particulate matter is not mentioned in the book, "pollution" is one of the most common words with 101 hits.

Once again, we have a more general term discussing something that may not have been discussed as much at the time, as particulate matter measurements and their potential harm became a much more well-known phenomenon later. This can be seen in the EPA's regulation changes in the 1990's, which elaborated the criteria for PM monitoring and restriction. [16]

Viewing the word "pollution" in the word tree allows us to easily assemble phrases where it appears. It is important to note that TLTG does mention many potential health problems that are caused by air pollution, such as:

"Major illnesses linked to air pollution include emphysema, bronchitis, asthma, and lung cancer."

"Pollution may affect the mortality of the population directly and indirectly by decreasing agricultural output."

"The death rates rise abruptly from pollution and lack of food"

There is another possible reason that may account for why TLTG does not discuss particular forms of pollution, and that is because from the word tree analysis of the book, it seems to discuss environmental problems with a general audience in mind. Perhaps for this reason, it did not discuss data which may not have permeated into the population at large at that time. Keep in mind; this was published at a time when even the dangers of smoking were not as well-known as they are now.

6 Discussion

The combination of data, visualization tools and trial and error allowed the team to conduct a weighty investigation of the questions introduced by TLTG and allowed for a quick and thorough update on the matter of resource scarcity and solutions to the related challenges. The powerful influence of "overview, zoom, filter and details on demand" [17], were employed by each team member to build a quality report. Team members definitely experienced a "dialog with the data" as described by Roberts [18] by working with many different tools and approaching the same subject matter from multiple angles.

The visualizations also tell the story [19] of how the state of global ecology has evolved since 1972. Recalling the work of Vannevar Bush, we also see the trail of thought [20] between TLTG and circular economics visualized in the alluvial flow diagram. The ManyEyes word tree also illustrates how terms and ideas from 1972 relate to the situation today, and how our understanding has changed. Stepping back, we are able to absorb the bigger picture and walk away with some conclusions.

The AQUEDUCT water risk tool takes a bit of examination in order to properly digest. The red areas immediately draw the eye, but many of these areas are in the desert regions where it would not be unusual to experience a water shortage. However, on closer examination when one looks at the orange colored regions which represent a medium to high water risk, we can see that many highly populated parts of the world are at risk: the western United States and the Eastern seaboard, much of Europe, large swaths of sub-saharan Africa, as well as great portions of China and Southeast Asia. Nearly all of India falls into medium to high water risk. From this visualization, it seems almost certain that water shortages are approaching. From an information analyst perspective however, this visualization is at first glance misleading and perhaps fails some of the Gestalt tests for perceptual ease and clarity [21].

From the air quality visualization, we observe that densely populated and industrialized countries are suffering the most. However, Europe, which is also very populated, appears to have better air quality. This may be due to their more service based economies. It may also be related to better environmental monitoring and remediation strategies. This seems to indicate that with some effort, areas in the red zones with poor air quality may be able to improve their air. However, the map also shows a great number of red dots over Iraq, and one has to wonder how much of that bad air has been caused by a decade-long war in that region.

7 Conclusion

In this project, multiple factors were examined as each of us analyzed the visualizations and attempted to find answers to our questions.

Greg Furman's focus was on air quality. He found that the visual representation of air quality does suggest that developing countries, such as India, may not have emissions standards in place to improve air quality. However, it was unclear from the visualization if the density of people in populous regions is the reason for poor air quality. As such, future data samples can be used in association with current samples to form a more collective data selection that can aid in better understanding population impacts on air quality. The use of such samples can aid and reinforce the value of emissions standard practices set forth by governments to help increase the quality of the air in their regions. The next topic deals with water resources.

Thai found the biggest challenge is that we are unable to determine what the actual global water capacity is. In his research, he uncovered regions which are at high risk for water shortage and may require attention in developing a water replenishment system. His research evaluated data over the course of time and it indicated that water usage has been increasing with no consistent water renewal system to help sustain the global need for water.

Brigitte's visualization uncovered the evolution of thought around resource limits and traced the patterns by comparing key terms from TLTG to concepts from the field of circular economics. The visualization shows that thinking has expanded beyond simply defining the problem and progressed into the development of solutions. Most interestingly, the field of system dynamics has emerged as a vector for change. The researchers in this emerging field are currently developing models that have the potential to develop intelligent responses to resource scarcity predicaments.

Joseph Foss' research utilized ManyEyes to show how the ideas in the book were related to the ideas behind the visualizations in the paper. Looking up the main terms helped reveal ideas behind the terminology that was used in the book. This is relevant as the book is from 1972, and many modern terms associated with the environmental movement were not established at that time.

With the visualization tools and raw statistical data, we may be able to draw some sort of conclusion based on our findings. If you take it into perspective, we were able to explore trends and make safe assumptions on what directions to take even with many different elements that are beyond our comprehension. Luckily, we are at a new age where vast amounts of information are readily at our fingertips and with the assistance of information visualization tools, we are better equipped and much more prepared for what is to come.

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