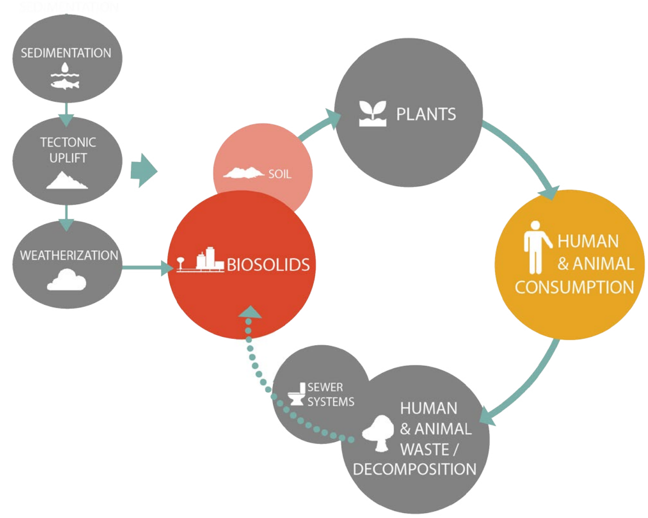
FROM WASTE TO PLATE: EXAMINING THE ROLE OF URBAN BIOSOLIDS IN RECYCLING PHOSPHORUS



A THESIS PRESENTED TO THE FACULTY OF ARCHITECTURE, PLANNING, AND PRESERVATION COLUMBIA, UNIVERSITY

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE MASTER OF SCIENCE IN URBAN PLANNING

MARLA WEINSTEIN
MAY, 2013

ABSTRACT

Phosphorus, a nutrient found in soil, is vital to plant life and therefore essential to our global food supply. Naturally recycled by ecosystem services, human cities have interrupted this cycle as phosphorus now accumulates in urban areas rather than returning to the land. In turn, we have turned to mined phosphates to supplement fertilizers and ensure our global food supply. As phosphorus deposits are a limited resource, however, we face future phosphorus shortages and threats to the security of our food supply.

Biosolids, or treated waste, is a byproduct of our sewage treatment system and represent an opportunity for phosphorus recovery and recycling. This research (1) examines the role of biosolids in replenishing the natural phosphorus cycle and reducing our dependence on mined-phosphates by (2) examining the case study of NYC biosolid management in order to gain insight that can be extracted and applied to other global cities. Ultimately findings suggest biosolids can relink the natural cycle, framing biosolids as a resource, rather than a waste, for urban areas and recommend cities promote biosolid demand through contracting, land application siting, and investments in nutrient recovery technologies.

ACKNOWLEDGEMENTS

A special thanks to:

Professor Elliott Sclar, Thesis Advisor
Professor Steve Cohen, Thesis Reader
Michael, Nancy, & Bethany Weinstein
Rebecca Kuss, Samantha Lazar, & Lorie Grushka

EXECUTIVE SUMMARY

Simply stated, ecosystem services are the benefits we receive from healthy functioning ecosystems. Supplied by the invisible ecosystem functions surrounding us, these services are often not thought of as being produced and consumed like other goods and services. One such eco-service we rely on is phosphorus cycling. Phosphorus, a highly toxic and reactive element, is vital to humans in its oxidized form, phosphate. The average human adult contains .7 kg of phosphates and intakes approximately 1,700 more milligrams per day. Phosphates support our bodies' metabolic, skeletal, and muscular processes. Yet most importantly, phosphorus is vital to plant life, and therefore essential to our food supply.

Like other goods, ecosystem services adhere to the economics of supply and demand. Without human interruption, phosphorus recycles itself, passing from soil to plants to humans, and back to the soil again in the form of waste and decomposition. With the advent of modern cities, we have interrupted this cycle. Modern sewer systems cause the phosphorus in our waste to accumulate in cities rather than return to the land, while modern agriculture places greater demand on phosphorus supplies. To supplement this broken cycle, we have become dependent on phosphorus mined from rock deposits, rather than phosphorus recycled in the natural system. Yet phosphorus rock is a limited resource that may not be able to meet a growing future demand, raising serious questions about the future of our global food security.

Biosolids, or treated waste, is a byproduct of our sewage treatment system and represents an opportunity for phosphorus recovery and recycling. Beneficial reuse is the application of biosolids to land, mimicking the natural cycle, reclosing phosphorus supply and demand, and reducing our need for mined phosphate fertilizer. This research (1) examines the role of biosolids in replenishing the natural phosphorus cycle and reducing our dependence on mined-phosphates by (2) examining the case study of NYC biosolid management in order to gain insight that can be extracted and applied to other global cities.

Ultimately findings suggest NYC biosolid beneficial reuse has declined in recent years as the city has adopted less expensive alternative means of biosolid management. Yet this research argues biosolids can become a resource, rather than a waste or cost, for urban areas, recommending cities promote biosolid demand through contracting, land application siting, and investing in nutrient recovery technologies.

BACKGROUND

THE ORIGINAL SUPPLY & DEMAND

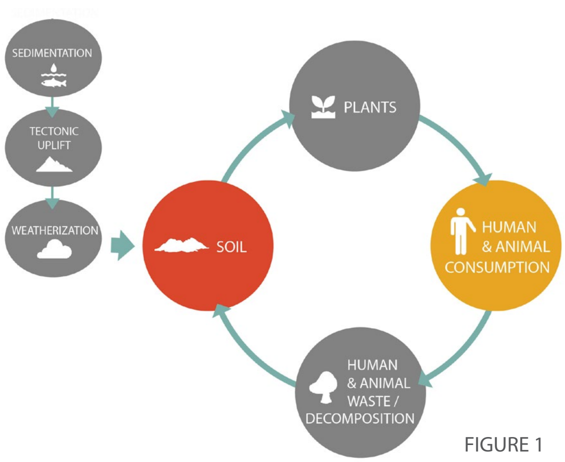


FIGURE 1

In an uninterrupted state, phosphorus recycles itself, creating a closed loop of supply and demand. Beginning as aquatic life that is buried and mineralized on the sea floor, the nutrient is found in land rock deposits after tectonic plate uplift. Weather and erosion break down these deposits, allowing phosphorus to enter the soil, a process spanning several million years.

The phosphorus entering the soil, however, is highly toxic to humans and animals, which require an oxidized form of phosphorus, known as phosphates. Ecosystem services provide a natural processing and consumption cycle, repeating on a weekly to yearly cycle. Plants are able to absorb the toxic phosphorus and process the nutrient into phosphates. Humans and animals then absorb the phosphates through the plants we (and the animals we consume) eat. To complete this cycle, human and animal wastes, along with plant and animal decomposition, return these nutrients to the soil.[1] This cycle creates an equilibrium between the phosphorus demanded by plants, animals, and humans, and the phosphorus supply fed by the waste and eventual decomposition of animals and plants. (see: Figure 1)

CURRENT SUPPLY & DEMAND

As human population has grown and cities expanded, we have interrupted this cycle, and in turn, upset the balance of phosphorus supply and demand. (see: Figure 2)

SUPPLY

In many cities, human waste, known as "night soil," was originally returned the land. City expansion however, meant the distance to agricultural land, along with the amount of human waste, grew. As waste was no longer returned to the land, sewage accumulated in cities, often thrown into the streets and washed away into local water bodies. This form of open disposal eventually bred disease epidemics in cities across the world. The connection between disease, water, and sanitation was eventually cemented after an 1854 cholera outbreak in London. As Europe began to modernize their waste management in response, America followed. Waste, and the phosphorus it contained, now enters wastewater treatment systems and accumulates in urban areas rather than returning to the land.[2]

Additionally, modern industrial agriculture practices begin to harvest crops before they are able to decompose and return nutrients to the ground. Ultimately, waste and decomposition no longer feed phosphorus supply, creating a potential deficit of supply unable to meet demand.

DEMAND

As the phosphorus cycle was now broken, to meet the growing food and phosphorus demands of the 20th century, we have turned to fertilizer to supplement the natural supply of phosphorus.

In the early 1900s, most of the world's phosphates came from international traded bones and guano excavated from the Pacific Islands.[3] Today, we have turned to chemical fertilizers that are mined from natural phosphate deposits consisting of phosphate rocks that have not yet eroded and entered in the soil. In essence, we have attempted to speed up supply, bypassing the natural recycling process by going straight to the source. (see: Figure 3)

Today, we are dependent on mined phosphorus for our global food supply. In 2011, over 190,000,000 metric tons of phosphate was mined and produced throughout the globe, continuing the trend of increased production.[4] World mining and production is mostly centered

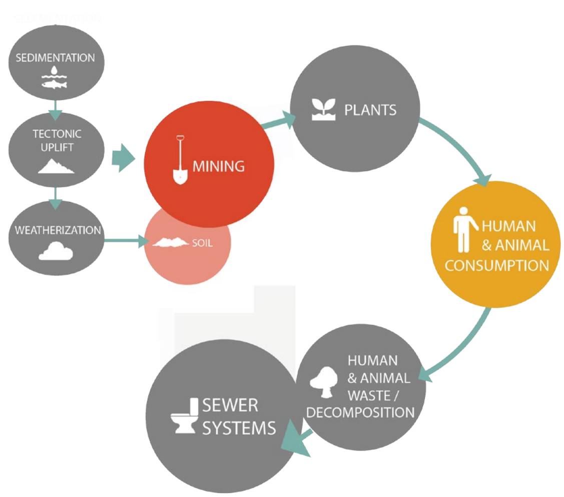


FIGURE 1
The natrual phosphorus cycle

FIGURE 2
Human interruption has led phosphorus to accumulate in urban areas. To meet supply we hav eturned to mining phosphorus from around the globe.

1 "Phosphorus," in Cambridge World History of Food, ed. Kenneth F. Kiple and Kriemhild Conee Ornelas (Cambridge, United Kingdom: Cambridge University Press, 2000).

2 K. Ashley, D. Cordell, and D. Mavinic, "A Brief History of Phosphorus: From the Philosopher's Stone to Nutrient Recovery and Reuse," Chemospher 84(2011).

3 Dana Cordell, Jan Olof Drangert, and Stuart White, "The Story of Phosphorus: Global Food Security and Food for Thought," Global Environmental Change 19(2009).

4 Stephen Jasinkski, "Phosphate Rock," in Mineral Commodity Summaries (US Geological Survey, 2012).

in five countries, Morocco, China, US, Russia, and Tunisia. Morocco, the third largest producer, is currently the largest phosphate exporter, often the sole supplier to a country, for example, India.[5] The US is responsible for approximately 19% of the world's phosphorous consumption. Since 1960, the US has applied approximately 223 million tons of phosphorus, or an average of 4 million tons per year, on approximately 85% of crops grown.[6] Approximately 65% of the phosphorus used on US land is mined in Florida, home to four counties which produce, on average, over 30 million tons of phosphate rock per year.[7] This rock is then processed, mixed into fertilizer, and enters the country's food system. (see: Figure 4)

EXTERNALITIES

Mining has served as link, bridging the gap between supply and demand. Yet while managing to meet demand, mining simply subsidizes the natural supply rather than reestablish the natural cycle. This broken cycle reinforces our dependence on mining, leading to externalities, or third party costs, on the environment.

WATERBODIES

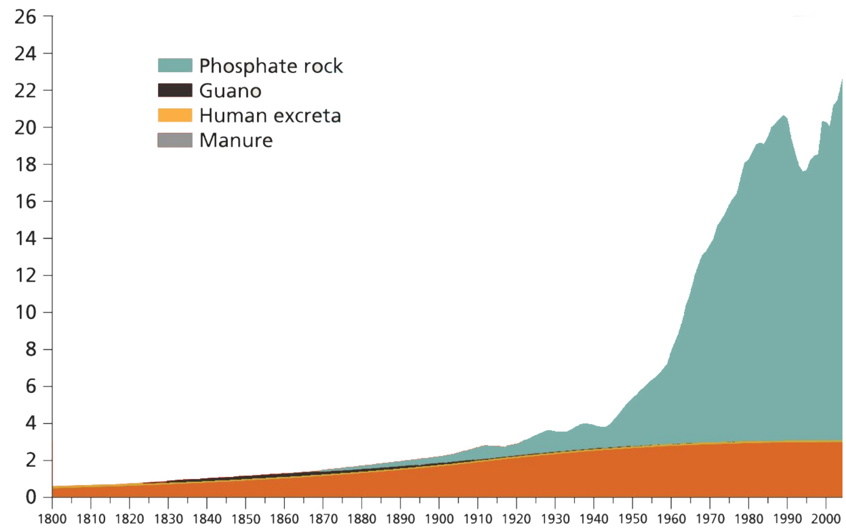
Mined-phosphate fertilizers are used to grow more plants and feed more animals needed for human consumption. Once consumed, however, the phosphorus again accumulates in urban centers as it enters the waste stream. And once in the wastewater treatment process, phosphorus is often discharged to local bodies where it joins phosphorus from fertilizer runoff, disrupting marine cycles. Human interruptions to the global phosphorus cycle have quadrupled the amount of phosphorus in ocean waters.[8] New York City can serve as an example of the costs a broken phosphorus cycle can have on local waterbodies, such as Jamaica Bay.

5 James Elser and Suart White, "Peak Phosphorus, and Why it Matters," Foreign Policy (2010).

6 USDA, "National Agricultural Statistics Service " (2012).

7 David Vaccari, "Phosphorus Famine: The Threat to Our Food Supply," Scientific American (2009).

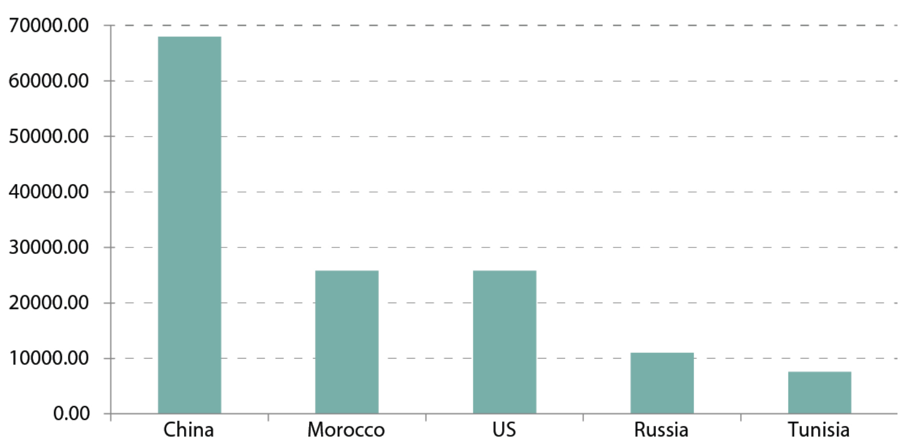
8 Genevieve Metson, Elena Bennett, and James Elser, "The Role of Diet in Phosphorus Demand," IOP Science 7, no. 4 (2012).



PHOSPHORUS USE PER YEAR (MILLION TONS) BY TYPE

*Dana Cordell, Jan Olof Drangert, and Stuart White, "The Story of Phosphorus: Global Food Security and Food for Thought," Global Environmental Change 19(2009).

FIGURE 3:
Shows transition from manure to phosphate rock from 1850 to today.



2010 TOP 5 GLOBAL PRODUCERS OF PHOSPHATE (TONS)

*Source: World Bank

FIGURE 4:
Global Phosphate production is centered in 5 countries, raising questions about future distribution and access

NYC first began construction on the city's sanitation system in the late 1800s motivated by health and safety concerns. Accordingly, the city strategically sited wastewater treatment plants along popular beaches in attempts to prevent the spread of disease. The 26th Ward and Coney Island water pollution control plants (WPCPs) were the first of 14 plants built. By the early 1900s two more plants, Jamaica Bay and Rockaway surrounded Jamaica Bay as well. By 1890, over 1.5 million people were sending their waste to these 4 plants. The wastewater, along with the nutrients it contained, was treated before being discharged into the bay, Jamaica Bay, situated within Brooklyn and Queens connecting the Lower New York Bay to the Rockaway Inlet, contains low lying salt marshes, prime habitat for fish, avian, and plant life.[9] [10]

Just as phosphorus and nitrogen spur terrestrial plant growth, nutrient loading into water sources promotes excessive algae and weed growth. As this additional plant life matures and dies, decomposition draws oxygen from the water, resulting in hypoxia, areas of depleted oxygen levels that can no longer support aquatic life. These "dead zone" conditions can worsen during the summer as warmer water can hold less dissolved oxygen and algae becomes more active.

By 2000, water treatment facilities had become the greatest sources of carbon, nitrogen, and phosphorus to Jamaica Bay. According to state standards, the dissolved oxygen levels in Jamaica Bay have been at safe levels for the past 20 years. Yet eutrophication is often an issue of nutrient distribution, not nutrient quantity. Hypoxia is most prevalent in areas that receive discharge from wastewater treatment plants, especially where these plants are the main source of fresh water to the waterbody. Today, over 300 million gallons of treated effluent is discharged into the bay, representing the largest contribution of fresh water to the bay. Additionally, city dredging has reduced the already low flushing, or resident time of Jamaica Bay. Measured as the amount of time it takes for one particle of water to circulate through the bay, low resident time means nutrients will remain in the bay for longer.[11] [12] (see: Figure 5)

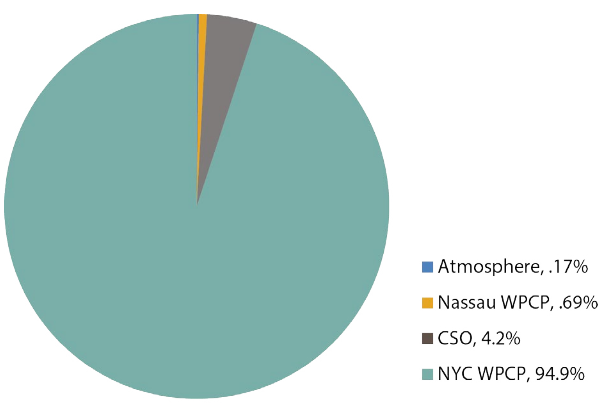
This in turn, is a contributing factor explaining the current loss of Jamaica Bay marshland. During the 1990s, the Bay's marshland began to deteriorate at a rate double that of the previous four decades, directly corresponding to increases in nutrient loading. Ultimately, nutrient loading from the surrounding treatment plants has led to the encroachment of Sea Lettuce (*ulva lactuca*) into the low marshes of Jamaica Bay. Sea Lettuce in turn, covers the stalk and impedes the growth of Saltmarsh Cordgrass (*spartina alterniflora*) which is vital to marsh stability. The interwoven root network of the grass increases soil strength, that when compromised by sea lettuce, results in marsh deterioration. This deterioration in turn, has

9 Marie L. O'Shea and Thomas M. Brosnan, "Trend in Indicators of Eutrophication in Western Long Island Sound and the Hudson Raritan Estuary," Estuaries 23, no. 6 (2000).

10 John M. Rhoads et al., "Noton Basin/Little Bay Restoration Project: Historical and Environmental Background Report," (New York: U.S. Army Corp of Engineers, 2001).

11 Keith R. Cooper and Marija Borjan, "Northeast Coastal and Barrier Network Assessment of Containimant Threats," ed. U.S. Department of the Interior (Colorado: National Park Service, 2010).

12 New York- New Jersey Harbor & Estuary Program, "The State of the Estuary 2012: Environmental Health and Trends of the New York-New Jersey Harbor Estuary ".



PHOSPHORUS LOADING TO JAMAICA BAY

*Source: NY-NJ Harbor Estuary Program

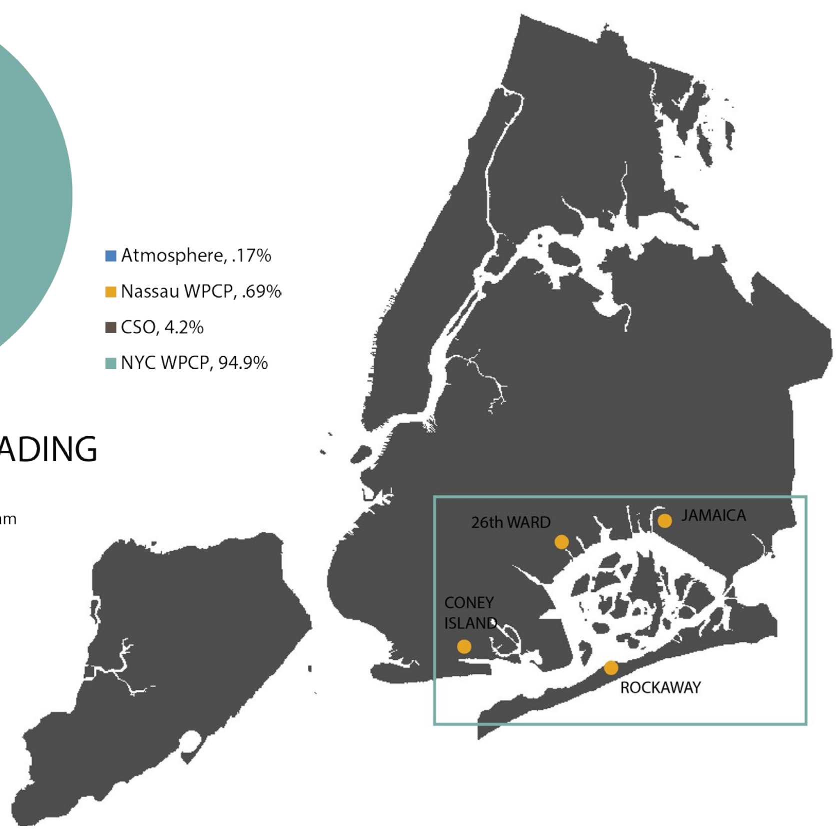


FIGURE 5: Nutrient loading into local water bodies, such as Jamaica Bay, has led to eutrophication and resulting dead zones.

far reaching consequences. Jamaica Bay not only serves as habitat for fish species and migrating birds, but plays a vital role in mitigating flooding, preventing shoreline erosion, and filtering pollutants out of the water. This may have severe consequences as the city faces the threat of rising sea levels and extreme weather conditions.[13 14]

Recently the city has taken steps to mitigate eutrophication and ensure the safety of local waterbodies. In 2010, New York State (including NYC), enacted the Dishwasher Detergent and Nutrient Runoff Law in attempts to reduce nutrient runoff. The legislation bans dishwasher detergents and other household cleaners that contain more than .67 phosphorus. Additionally, because the city employs a combined sewer system, much of the phosphorus entering the system stems not from human waste, but from runoff. Therefore law also restricts the amount of phosphorus allowed in fertilizer, along with mandating retailers to display fertilizer with phosphorus separately from those that do not.[15]

New York has taken the first steps to limit and repair marine dead zones, which should be replicated on a global scale to combat the far-reaching impacts of a broken phosphorus cycle.

MINING

Our dependence on mining has also led to other environmental externalities. A resource intensive process, phosphate mining employs strip mining. This technique immediately requires the removal of 20 to 40 ft. of surface area in order to first reach phosphate deposits. Ultimately, over 100 tons of material, or overburden, is removed for every one ton of phosphate produced. After phosphorus is mined, it enters a process of beneficiation, which upgrades the phosphate content by removing contaminants. Ultimately, mining and beneficiation are disruptive, intensive processes that pose threats to local water, air, and land resources.

Both the mining and beneficiation processes require massive amounts of water. In 2012, Mosiac, one of the state's largest mining companies, requested a 20 year permit allowing the company to withdraw over 69 million gallons of groundwater per day. Lowering reserves and increasing the risks of sinkholes, this resource use also prevents freshwater from flowing down-stream. This in turn can change the salinity of local water bodies and in turn disrupting marine ecosystems, for example Peach River, one of the state's major sources for drinking water. Phosphate mining also risks leaks and contamination not just to local water bodies, but to land as well in the form of erosion, leakage, and weathering from mine sites.

Phosphogypsum, a processing byproduct, poses a constant threat of contamination. With each ton of phosphate generating approximately 5 tons of phosphogypsum, Florida is currently home to over 25 stacks, reaching 200 ft. or higher, containing the approximately 300 million tons of phosphogypsum produced each year. These stacks can leak and contaminate local areas, costing the state millions of dollars. In the early 2000s, Florida was required to spend over $200 million to clean up Piney Point in North Manatee County after a storm caused a local gypstack to leak.[16 17 18 19]

In Florida, phosphate mining companies own the rights to over 400,000 acres, of which 340,000 have been mined but only 70,000 have been environmentally restored.

As we have broken the natural phosphorus cycle and relied on mined-phosphates to meet demand, similar environmental externalities from mining have been noted across the globe.

13 Ellen Hartig et al., "Anthropogenic and Climate Change Impacts on Salt Marshes of Jamaica Bay, New York City," Wetlands 22, no. 1 (2002).

14 Gateway National Recreation Area and Jamaica Bay Watershed Protection Plan Advisory Committee, "An Update on the Disappearing Salt Marshes of Jamaica Bay, New York," ed. U.S. Department of the Interior (2007).

15 New York State, "New York State Law Restricts Use of Lawn Fertilizers Beginning January 1, 2012," ed. Department of Environmental Conservation (New York2012).

16 United Nations Environment Programme and International Fertilizer Industry Association, "Environmental Aspects of Phosphate and Potash Mining," (2001).

17 Cordell, Drangert, and White, "The Story of Phosphorus: Global Food Security and Food for Thought."

18 Dr. H. El-Shall et al., "In-Situ Mining of Phosphate Ores," (Department of Materials Science and Engineering University of Florida 2004).

19 International Fertilizer Industry Association, "Florida Phosphate Mining," http://cenvironment.blogspot.com/2010/11/florida-phosphate-mining.html.

Figure 6:
Mining, a resource intensive process, poses threats to local water, air, and land resources

FUTURE

As we have moved away from the natural phosphorus cycle, we have become dependent on mined-phosphate based fertilizer to maintain a façade of equilibrium between phosphorus supply and demand. Modern agriculture, and in turn society, has become dependent on mined-phosphate to spur our global food supply. Yet this system is unsustainable. As we enter a new phase of global growth, and therefore growing phosphorus demand, we face a future of dwindling phosphorus reserves. (see: Figure 9)

DEMAND

The global demand for mined phosphate is only increasing. Currently, food production demands 90% of the current global phosphorus production, requiring over 150 million tons of phosphate rock per year to sustain the system. As our global population rises, so does the demand for food and phosphorus. By 2007, the global demand for phosphates had already increased 198% from 1961 levels. This increased demand stems not only from a growing population, but one whose diets are changing as well.

Increasing affluence is creating a global diet that is more reliant on meat products. In 2007, global meat production reached 275 million tons, tripling over the last 4 decades, and is expected to double again by 2050.[21] Meat diets in turn, however, require even greater quantities of phosphate than their plant-based diet counterparts. Meat consumption represents the largest factor affecting P footprints, accounting for 72% of the global average P footprint due to plant- based livestock feed and other inefficiencies. Since 1961 global per capita phosphorus use has increased over 38% (1.9 to 2.6 kg per person), and will continue to do so. Based on continued changes in diet and future population projections, overall demand for phosphate is estimated to be expanding approximately 3% per year.[22 23]
(see: Figure 7)

SUPPLY:

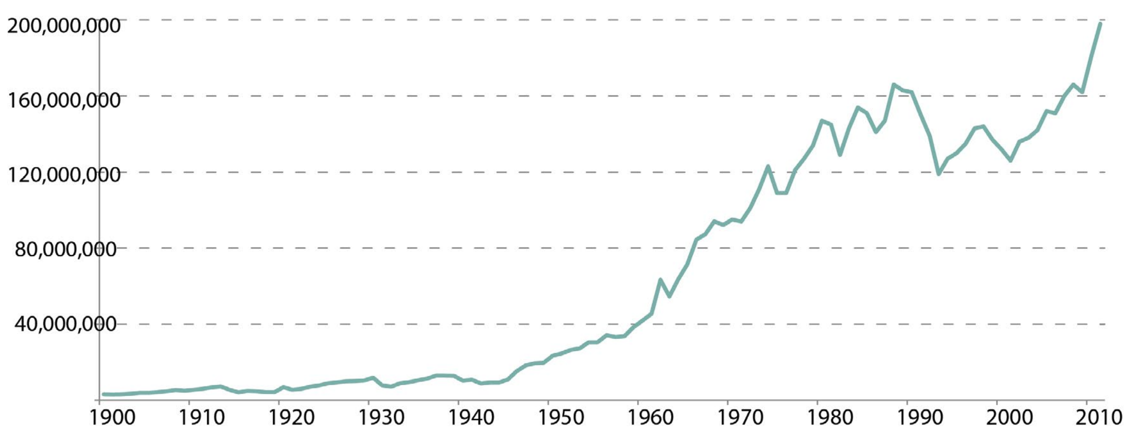
Yet as demand grows, questions arise if our limited supply can meet this demand. Phosphorus is a limited resource that, unlike oil, does not yet have a substitute. Yet similar to Hubbert's peak oil, peak phosphorus does not refer to a time

20 Metson, Bennett, and Elser, "The Role of Diet in Phosphorus Demand."

21 U.N Food and Agriculture Organization, "Meat and Meat Products," Food Outlook, June 2008.

22 Metson, Bennett, and Elser, "The Role of Diet in Phosphorus Demand."

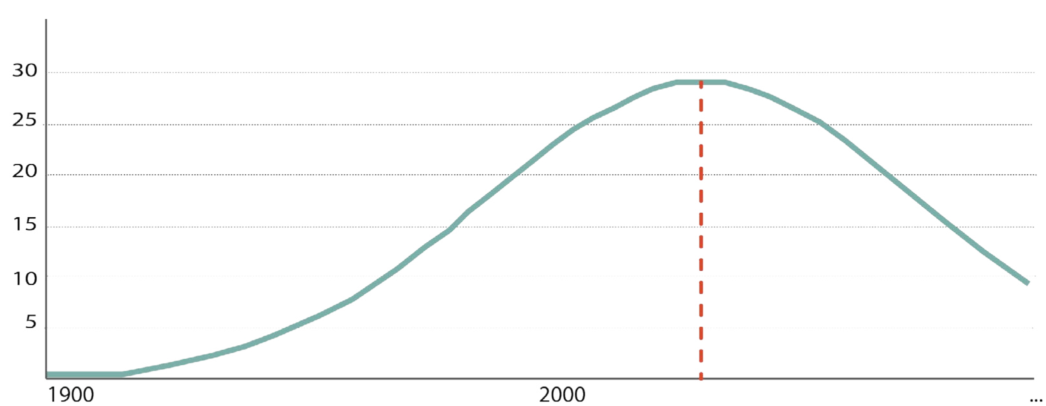
23 Elser and White, "Peak Phosphorus, and Why it Matters."



WORLD PHOSPHATE ROCK PRODUCTION (TONS)

*Source: USGS

Figure 7: Demand for phosphorus has greatly expanded since 1960 and appears to be continuing on this trend



WORLD PHOSPHATE ROCK PRODUCTION (TONS)

* D. Cordell et al., "Towards Global Phosphorus Security: A Systems Framework for Phosphorus Recovery and Reuse Options," Chemosphere 84(2011)

Figure 8: Peak Phosphorus refers to a time when production reaches a maxcimum, and high quality, highly accesible reserves have been depleted

when all sources are depleted, but rather when production reaches a maximum and high quality, highly accessible reserves have been depleted. As easily accessible sources are depleted, operations must turn to deeper, untapped deposits containing more impurities that increase the cost of extraction, processing, and especially transportation.

35 countries currently produce phosphate rock, with another 15 countries widely believed to contain reserves.[25] In 2011 the USGS estimated over 71 million tons of reserves remained worldwide, and over 300 billion tons of resources, or low-grade deposits.[26] Estimations vary, and how reserves translate into peak phosphorus years depends on the size, quality, and extraction rate of these resources. While some independent researchers believe peak phosphorus may occur as early as 2030, others, such as the International Fertilizer Development Center, estimate as long as 300 years.[27](see: Figure 8)

Ultimately, it is unclear exactly when, or even if, peak phosphorus will occur. It is clear, however, the supply of high-grade reserves is becoming increasingly limited to meet increasing demand. Currently 4.6 kg of rock is needed to produce .6kg of phosphorus and this is only expected to rise.[28] As high-grade phosphorus deposits dwindle, even larger volumes of rock will be needed to produce the same output, along with larger energy inputs, processing, technology, and transportation.

SUPPLY & DEMAND EQULIBRIUM

Ultimately increasing demand facing a limited supply will result in a phosphorus shortage. Rising costs of mining, along with unmet demand, will eventually trickle down, inflating the costs of phosphates, fertilizer, and eventually food. As summarized by the UNEP,

> ""If the phosphate concentration in the rock declines and larger volumes of ore are needed in order to obtain a given amount of phosphorus, production costs will likely increase. Such changes could also lead to greater energy requirements and more waste in phosphate rock mining. In an open market these factors might well raise the price of phosphorus fertilizers, limiting their accessibility to many farmers and having negative effects on yields. If these were to occur, food security could be threatened in countries that are highly dependent on phosphorus imports."

RESPONSE

Ultimately, in the face of a shortage we can adapt our demand, limiting our use, or focus on the supply-side, utilizing alternatives. While phosphorus does not currently have an alternative to supplement supply, it can be re-used. Where the modern sewer system first broke the natural phosphorus cycle, we can attempt to reconnect this cycle by returning human waste to the land in the form of biosolids.

BIOSOLIDS

The term "biosolid" emerged after a 1991 Water Environment Federation (WEF) contest to coin a term for treated sewage sludge that can be recycled. Today, biosolids are defined as nutrient rich, semi-solid material, which can be beneficially applied to land as a soil conditioner and fertilizing agent. Biosolid land application is a form of resource recovery that, rather than allowing phosphorus to accumulate in urban areas or landfill, recycles nutrients back into the soil. Beneficial application

24 Mark Evans, "Phosphate Resources: Future for 2012 and Beyond" (paper presented at the 18th AFA International Annual Fertilizer Forum & Exhibition, Sharm El-Sheikh, Egypt, 2012).

25 United Nations Environment Programme, "Phosphorus and Food Production," in UNEP Yearbook 2011 (United Nations 2011).

26 Jasinkski, "Phosphate Rock."

27 D. Cordell et al., "Towards Global Phosphorus Security: A Systems Framework for Phosphorus Recovery and Reuse Options," Chemosphere 84(2011).

28 Cordell, Drangert, and White, "The Story of Phosphorus: Global Food Security and Food for Thought."

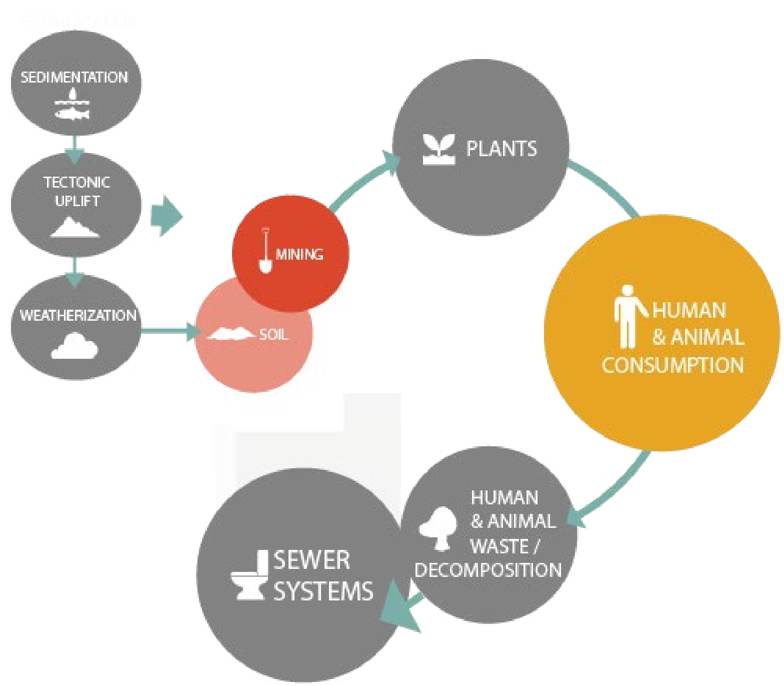


Figure 9: Increasing demand faces future mining limitations, leading to potential phosphorus shortages in the future.

of biosolids mimics the natural cycle, reclosing the supply and demand cycle and reducing our need for mined phosphate fertilizer.[29]

Almost 100% of the phosphorus we consume is excreted in our waste. Currently biosolids can remove 90% or more of this phosphorus from sludge. Therefore the approximately 3 million tons of phosphorus globally consumed per year, can theoretically, return to the land.[30] As such, biosolids cannot meet out current, let alone future, needs, however, can provide an easy and quick buffer against future shortages as part of a larger approach to the future state of phosphorus. (see: Figure 10)

PROCESS

Biosolids begin as liquid sludge output from wastewater treatment plants. After being sent to dewatering facilities, the liquid sludge is sent through centrifuges, removing much of the water and reducing volume. While some of the resulting biosolids may be directly applied to land, most biosolids require further processing to meet standards established by the EPA in 1994.

Developing out of risk assessments beginning the 1970s, EPA "Part 503" regulations set requirements for the final use and disposal of biosolids for both the biosolid preparer and applier.[31] [32] All biosolids used for beneficial reuse must be tested and meet pollutant limits, pathogen requirements, and vector attraction reduction requirements. iosolids are often referred to in terms of Class A or Class B which refer to specific bacteria density requirements. The EPA provides a list of alternative processes for achieving Class A Biosolids.[33] These include:

DIRECT LAND APPLICATION:

Biosolids are monitored throughout the digestion processes of the wastewater treatment process, have met all 503 requirements, and may be directly applied to land following dewatering.

ALKALINE STABILIZATION:

Alkaline materials, such as lime or cement kiln dust, are added to sludge resulting in a chemical reaction that generates heat and increases the pH level, eliminating pathogens in the biosolids.

COMPOSTING

Composting mixes biosolids with bulking agents, such as wood chips, allowing more oxygen to penetrate the mixture and encouraging decomposition. The resulting compost is similar to moss and is used as mulch or soil conditioner.

THERMAL DRYING

Thermal drying heats biosolids to heat temperature, removing moisture and killing pathogens. The process results in fertilizer pellets that can be applied to land.

While the EPA 503 guidelines provide requirements and safety standards for biosolid use, the specific location and type of application is currently decided by municipalities. Exploring the history of beneficial biosolid reuse in a large metropolitan area, like NYC can provide insight into how this practice can be applied across global cities to rebalance phosphorous supply and demand in the face of future shortages and current water body impacts.

29 North East Biosolids and Residuals Association, "Offical Usage of the Term "Biosolids"," (2008).

30 Cordell, Drangert, and White, "The Story of Phosphorus: Global Food Security and Food for Thought."

31 John Walker, Lynn Knight, and Linda Stein, "A Plain English Guide to the EPA Part 503 Biosolids Rule," ed. US EPA Office of Wastewater Management (Washington, DC1994).

32 Jim Ippolito and Bob Brobst, "The Science of Biosolid Land Application," (2012).

33 Walker, Knight, and Stein, "A Plain English Guide to the EPA Part 503 Biosolids Rule."

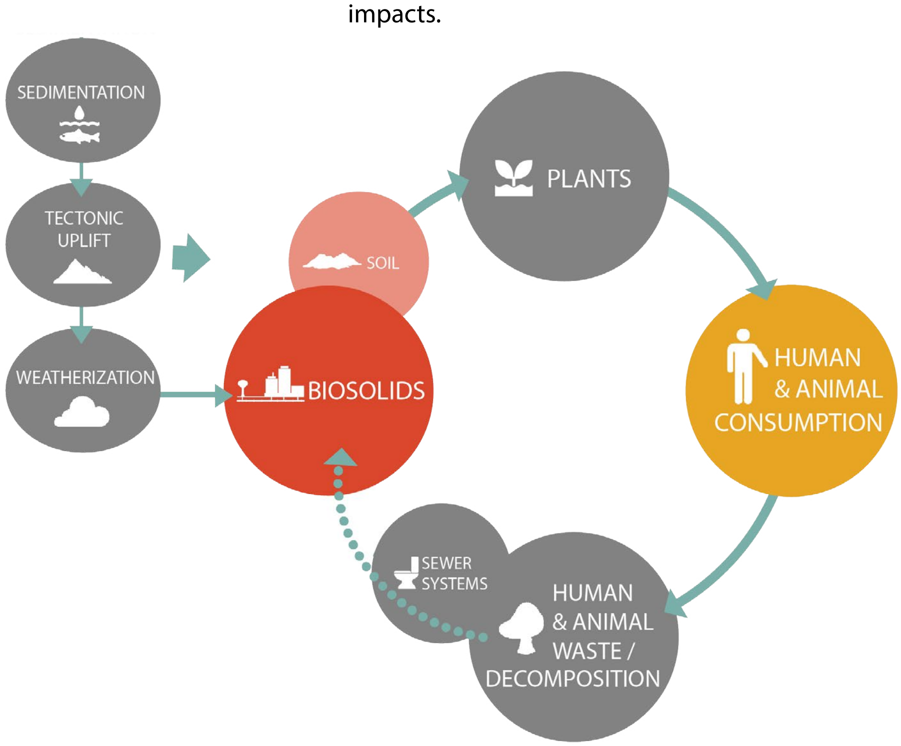


Figure 10: Biosolids represent an opportunity to recycle phosphorus, re-linking the natural cycle and reducing our dependence on mined phosphate fertilizer

METHODOLOGY

This research explores if re-use of biosolids through agricultural land application can replenish the natural phosphorus cycle and reduce dependence on mined-phosphates, examining the case study of NYC biosolid management in order to gain insights that can be extracted and applied to other global cities.

(see: Figure 11)

To do so, this research builds off existing literature, along with relying on city records and interviews with individuals involved at each level of the biosolid management process.

DATA

Analysis was conducted from city records including NYC Department of Environmental Protection Requests for Proposals, and 503 EPA Reports.

INTERVIEWS

Interviews were conducted at the city, contractor, and distributor level, providing insight into NYC biosolid management and opportunities for future resource recovery:

Interviews were undertaken with employees in the NYC DEP Bureau of Wastewater Treatment. The Bureau is responsible for the city's 14 water pollution control plants along with the NY Harbor and other local water bodies. Interviewees were employees responsible for contracting out city biosolid processing to private contractors, along with putting together the EPA 503 report, which will be discussed below.

Interviews were also conducted with managers at 2 of the private companies the city contracts with. WeCare and Tully Environmental both accept NYC biosolids, which are beneficially reused or landfilled.

Lastly, an interview was also completed with a sub-contractor, Parker Ag, located in Limon, Colorado. Parker Ag was responsible for the processing and distributiong of biosolids to farmland in Lamar, CO.

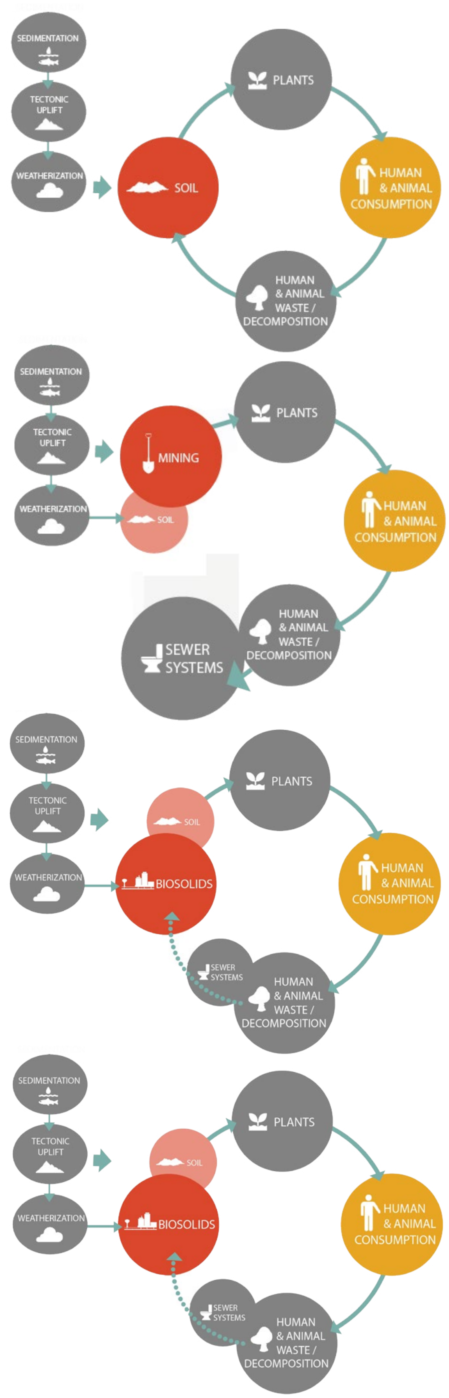


Figure 11:
This research explores the role of biosolids in relinking the natural phosphorus cycle, examining the case study of NYC biosolid management

FINDINGS
NYC BIOSOLIDS

New York City first began to actively address the city's growing sewage problem in 1884, redirecting sewage to stream banks for eventual discharge into local water bodies. Resulting in a deteriorated harbor, the city relocated waste dumping to the ocean beginning in 1938. This practiced continued until 1992, discontinued with the enactment of the federal 1988 Ocean Dumping Ban Act.[34 35]

In response, the NYC Department of Environmental Protection established the 1990 Sludge Management Plan to deal with the 1,200 tons of wet sludge the city produces daily. The plan's first initiative was the siting and construction of dewatering plants at 8 of the 14 wastewater treatment plants. The plan also let to the establishment of contracts between the city and private companies to process and beneficially reuse all city biosolids.[36]

Between 1998 until 2009, the city entered into over 13 different contracts that committed to 100% beneficial reuse of city biosolids. Based on EPA reports from 2004, 2006, 2007 and 2008, the city recycled anywhere from 100,000 to 150,000 tons of biosolids per day, applied throughout the US including grazing land in Virginia, agricultural land in Colorado, citrus groves in Florida, and even desert reclamation and gardening in Oman, United Arabic. [37 38 39]

The 1990 Sludge Management Plan completely revamped the city's approach towards sludge disposal, promising 100% beneficial reuse of all biosolids. To achieve this, the city entered into 6 contracts including three long-term 15-year contracts and three shorter, 5-year agreements. Ultimately, the city believed a combination of terms would,"…provide the stability of a long-term contract with well developed markets and the cost effectiveness of short-term contracts that can respond to emerging market opportunities."

The three 15-year contracts were entered into with three private contractors: Environmental Protection and Improvement Control (EPIC), New York Organic Fertilizer Company (NYOFCo) and Tully Environmental (Tully). These three contracts, described below, together became the foundation of NYC biosolid management, accounting for much of NYC biosolid history and beneficial reuse:

1. R.J. LONGO CONSTRUCTION CO. INC, ENVIRONMENTAL PROTECTION AND IMPROVEMENT CONTROL, EPIC (947ADM1), SET TO EXPIRE 2013

EPIC, owned by Synagro, entered into its first contract with the city in 1998, responsible for 225 to 510 wet tons of NYC sludge per day. Synagro, in turn, subcontracted processing and distribution to ParkerAg in Prowers County, Colorado. Transported from NY to Colorado, biosolids were applied to wheat crops and grazing land in Colorado, along with further land application in Virginia. The biosolids were original directly applied to agricultural lands, however, beginning in 2004, were treated with liming material (alkaline stabilization) by ParkerAg at a Colorado facility.[40 41]

Over the past 15 years, the EPIC (1) contract has been responsible for the beneficial reuse of approximately 20% of NYC biosolids per year.[42 43 44]

2. NEW YORK ORGANIC FERTILIZER COMPANY NYOFCO (947ADM4), SET TO EXPIRE 2013

NYOFCo, also owned by Synagro, entered into an original contract with NYC in 1998, Constructing a thermal drying fertilizer pellet facility in Hunts Point, Bronx, the resulting fertilizer pellets were sold nationwide, primarily applied to citrus groves in Florida.

Throughout the 15-year contract, NYOFCo has been responsible for almost half of New York City biosolid processing and application.

3. TULLY AND HYDROPRESS ENVIRONMENTAL SERVICES, INC TULLY (947ADM3), SET TO EXPIRE 2013

Entered into in 1998 and enacted in 1992, the contract appropriated 100 to 200 wet tons per day of city biosolids to Tully. Trucked to the company's composting facilities in Good Springs, Pennsylvania, the biosolids were processed with a combination of alkaline stabilization and composting. The resulting biosolids were employed for mine reclamation, restoring nutrients to landscapes deteriorated by mining practices.[45]

Tully has been responsible for anywhere between 12 to 19% of NYC biosolid beneficial reuse over the 15 year contract period.

34 NYC Department of Environmental Protection, "New York City's Wastwater Treatment System."

35 Ippolito and Brobst, "The Science of Biosolid Land Application."

36 World Environmental and Water Resources Congress 2010: Challenges of Change, (American Society of Civil Engineers, 2010).

37 NYC Department of Sanitation, "Attachment V: Biosolids, Medical Waste and Dredge Spoils Management," in Solid Waste Management Plan (2004).

38 NYC Department of Sanitation, "Attachment V: Biosolids, Medical Waste, and Dredge Spoils Management," in Solid Waste Management Plan (2006).

39 Bureau of Wastewater Treatment Biosolids Management, "US EPA 40 CFR Part 503: Use or Disposal of Sewage Sludge 2007 Annual Report," (NYC Department of Environmental Protection, 2008).

40 ParkerAg Compliance Manager Luke Bond, Interview, February 7 2013 2012.

41 LLC Parker Ag Services, "Services," http://www.parkerag.com/Profile/About.htm.

42 Sanitation, "Attachment V: Biosolids, Medical Waste and Dredge Spoils Management."

43 Sanitation, "Attachment V: Biosolids, Medical Waste, and Dredge Spoils Management."

44 Biosolids Management, "US EPA 40 CFR Part 503: Use or Disposal of Sewage Sludge 2007 Annual Report."

**For more information on NYC biosolid contracting please see Appendix A

These three long-term contracts became the foundation of the city's biosolid management program. Together, accounting for over 70% of NYC biosolid management since 1998, the contracts reflected the city's commitment to biosolid re-use.[46] Supplemented by short-term contracts that typically rotated on a three-year basis, the city managed to beneficially reuse all New York City biosolids between 1998 and 2009.

By 2012, however, beneficial reuse of city biosolids had fallen to just 18%. The beginning of the decline of recycling practices can be traced back to 2009 with the city's early termination of the NYOFCo contract and the nearing end dates of the other two contracts. As the city looked to new contracts, it began facing the extended financial crisis that was sweeping across the country, changing the future direction of the city biosolid management program.

NYOFCO CLOSING

The NYOFCo contract, set to expire in 2013, was terminated early by the city in 2010. The contract, one of the original long-term contracts, sent NYC biosolids to the company's thermal drying facility in Hunts Point, Bronx, where it was further processed into fertilizer pellets and applied to citrus groves in Florida, agricultural land in Colorado, and even as cover for desert reclamation in Oman, UA. By the time of its closing, NYOFCo was responsible for almost half of the city's annual biosolid management.

Following the early termination, the city immediately began to search for a replacement contract. By the following December 2011, the DEP had awarded a replacement contract with WeCare Organics. As described by a December 15, 2011 press release, under the new 5-year contract (still under agreement today), WeCare organics would be responsible for,

> "…bring(ing) up to 400 tons per day of biosolids to its processing site in rural eastern Pennsylvania where it will be stabilized with lime and made into a product suitable for beneficial reuse. WeCare will use the organic material for mine reclamation projects or sell it as compost to garden centers, nurseries, and landscape supply companies."[47]

As described, the WeCare Organics contract conveyed a continued commitment to beneficial reuse. As DEP Commissioner at the time, Cas Hollway stated at the announcement of the RFP,

> "…from fertilizer to energy, to building materials, and more, we know that sludge has many demonstrated beneficial uses, converting our sludge from waste to a valuable resource will move us closer to achieving Mayor Bloomberg's vision for a greener, greater New York."[48]

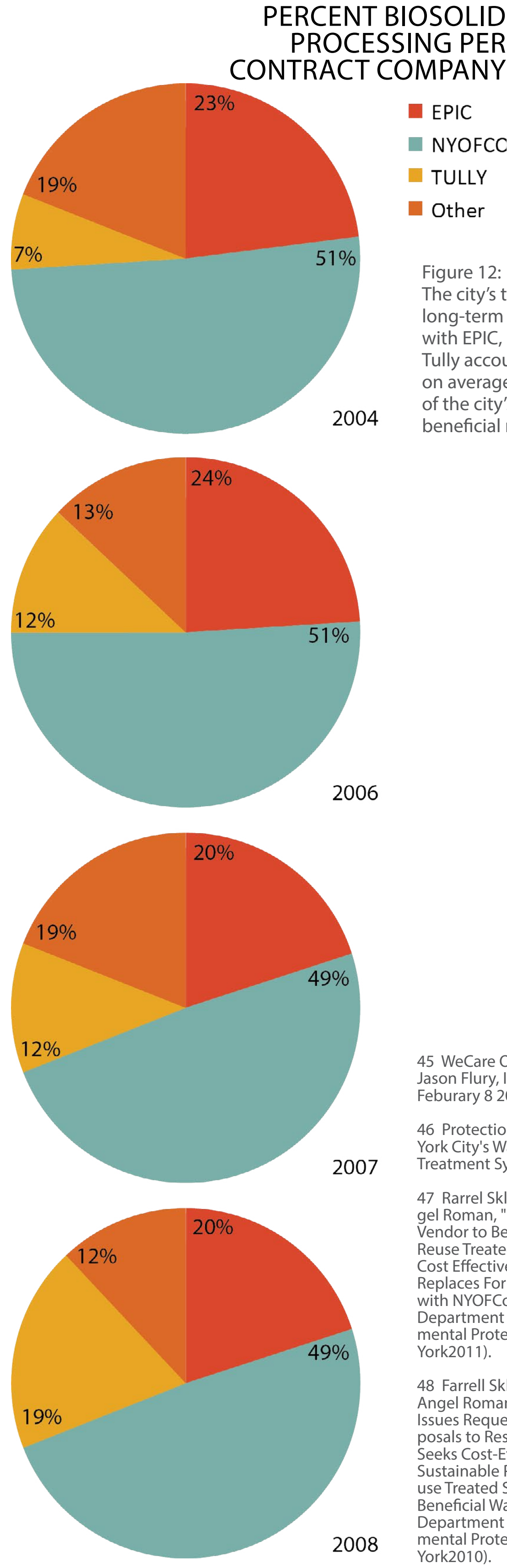


Figure 12: The city's three long-term contracts with EPIC, NYOFCo, & Tully accounted for, on average, over 70% of the city's biosolid beneficial reuse

45 WeCare Organics Jason Flury, Interview, Feburary 8 2013.

46 Protection, "New York City's Wastwater Treatment System."

47 Rarrel Sklerov and Angel Roman, "DEP Selects Vendor to Beneficially Reuse Treated Sludge: Cost Effective Program Replaces Former Contract with NYOFCo," ed. NYC Department of Environmental Protection (New York2011).

48 Farrell Sklerov and Angel Roman, "DEP Issues Request for Proposals to Resuse Sludge: Seeks Cost-Effective, Sustainable Program to use Treated Sewage in Beneficial Way," ed. NYC Department of Environmental Protection (New York2010).

BIOSOLID DECLINE

In reality, however, this commitment had fallen. At the time of its closing, the NYOFCo contract was responsible for the management of approximately 600 tons, or half of the city's total daily sludge production. Yet the new contract with WeCare only allocated 400 tons, or approximately one third of the city's total daily sludge, a 16% reduction for guaranteed beneficial re-use between the two contracts.

Additionally, as with all DEP biosolid contracts, the sludge amounts allocated represent a maximum allocation awarded to the contractor, not a guaranteed daily receiving amount. While the contract appropriated 400 daily tons, or 33% of the city's biosolids, by the end of 2012 WeCare Organics had only processed approximately 6,444.04 dry metric tons, or only 7% of the city's biosolids.

By the end of 2010 the city had lost its largest re-use contract, replacing it with a smaller contractor and diminishing the city's commitment to beneficial reuse. Additionally, the two other long-term contracts had dramatically changed as well. The original EPIC contract, traditionally responsible for approximately 20% of the city's biosolid beneficial reuse fell to just 1%, while the Tully contract previously responsible for anywhere from 12 to 20% of city biosolids, was reduced to 10%.

The city's struggling commitment to beneficial reuse was finally broken as the remaining two 15-year contracts expired at the end of 2012, replaced with four new contracts, currently in operation, all of which called for biosolid landfilling rather than beneficial reuse

With the early termination of the NYOFCo contract and sequential expiration of the remaining 2 long-term contracts, the city entered into 5 new, short-term contracts, currently in operation. These new contracts reduced the city's commitment to beneficial reuse, entering into agreements for landfilling instead. By the end of 2012, the traditional 100% beneficial reuse had fallen to just 18%, with the remaining 82% to landfills.

(see: Figure 13)

1. ENVIRONMENTAL PROTECTION & IMPROVEMENT COMPANY (1247-BIO)

While the previous 2 contracts entered into with EPIC both stipulated the beneficial reuse of NYC biosolids, this agreement calls for the transportation and disposal at the Atlantic Waste Disposal landfill in Sussex County, Virginia. In 2012, this contract was responsible for 23,901 dry metric tons of sludge, or approximately 24%.

2. COASTAL DISTRIBUTION (1250-BIO)

NYC DEP's contract with Coastal stipulates for the transportation and disposal of city biosolids to landfill. Originally contracted to the Brookville Landfill in Brookhaven, NY, the NYSDEC banned the landfill from accepting biosolid material in March 2011. Consequently, Coastal has begun subcontracting disposal to EPIC, who in turn contracts to landfills in Sussex County, Virginia. In 2012, Coastal was responsible for the disposal of approximately 28,236 dry metric tons, or 29% of the city's biosolids.

3. INTERSTATE WASTE SERVICES (1280-BIO)

NYC DEP's contract with Interstate allocates the transportation and disposal services for biosolids at landfills located in Amsterdam, Ohio. In 2012 Interstate was responsible for 28,326 dry metric tons, or 29% of NYC biosolids

4. TULLY ENVIRONMENTAL (1221-RDR)

A supplemental contract holding Tully responsible for biosolid transportation and disposal on an as-needed basis to landfills in Kersey and Harrisburg, PA. In 2012, this accounted for 21.65 tons of sludge, a negligible percentage

ANALYSIS

The reduction of biosolid beneficial reuse after 2010 was reflected at the state level as well. Similar to the city, state beneficial reuse fell from 45% to below 30% after 2010, with over 52% of the state's biosolids now being sent to landfill.[49] By 2011 the 26 permitted landfills in NY State were accepting over 90,000 dry tons of biosolids, as compared to 50,000 dry tons in 2004.[50]

Not coincidentally, at the same time, both the city and state were experiencing the full effects of the economic downturn plaguing the nation as a whole. Ultimately, beneficial reuse is considered to be a more expensive, and less publically accepted, form of biosolid management. In 2010 costs and economic factors played a driving force in the closing of the NYOFCo contract and criteria for future contracts. As a NYC DEP Bureau of Wastewater employee explained,

> "that's the way the tide swung. Under the fiscal constraints the city was facing, landfill was simply cheaper."[51]

THE COST OF BENEFICIAL REUSE

The NYC DEP's decision to close the NYOFCo Hunts Point plant was cost driven. While the plant had faced much opposition from the surrounding community, raising larger questions about facility siting and environmental justice concerns, ultimately, the contract's early termination was largely economical. As a December 2011 press release revealed,

> "…DEP terminated its contract with the New York Organic Fertilizer Company due to increasing costs in processing…At the time the contract was terminated, it cost approximately $30 million per year." [52]

Appropriating anywhere from 510 to 825 wet tons per day, the NYOFCo contract cost the city approximately $32,000,000 per year at signing, or approximately $100 to $175 per ton of city biosolid.[53] While the price of biosolid processing varies depending on the processing type, quantity, and contractor, on average, beneficial reuse contracts cost the city anywhere from $70 to $140 per ton.* These prices must take into consideration the transportation, processing, materials, insurance, and monitoring expenses associated with biosolid processing and beneficial reuse. [54]

Alternatively, landfilling is simply less expensive for the city. Unlike biosolid processing, the economics of landfilling simply breaks down into transportation costs and dumping fees, also known as tipping fees. Again, varying by state and landfill, tipping fees can range from $30-$80 per ton, with a national average of $43 per ton.[55]
In New York, the Mill Sea Landfill in Monroe County, currently accepting the largest quantity of NY State biosolids and representative of other state landfills, charges $48 per ton (2012).[56] Landfilling is not only cheaper, but often the easier option as well. Unlike biosolid application which requires both city and state oversight, daily monitoring, and yearly reporting, landfilling has limited long term liability and does not require the same permitting and regulatory oversight as beneficial reuse.

Ultimately, landfilling typically remains the less expensive choice for biosolid management and is therefore turned to by municipalities during economic downturns.

49 New York State, "Biosolids Management in New York State," ed. Department of Environmental Conservation: Division of Materials Management (Albany, NY2011).

50 Ibid.

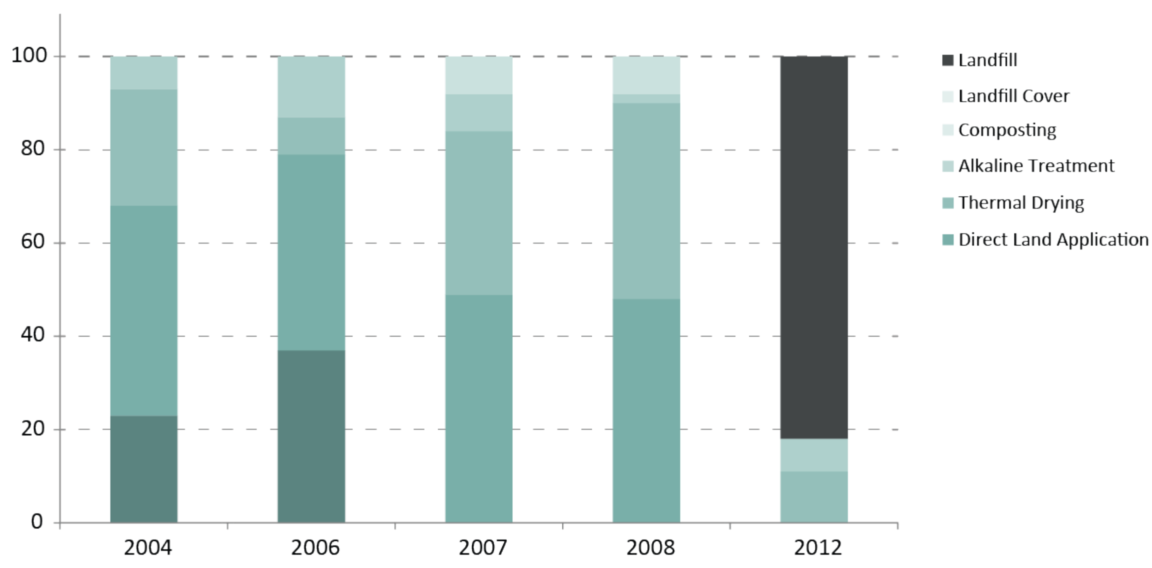
51 Beth Petrillo, 2012.

52 Sklerov and Roman, "DEP Selects Vendor to Beneficially Reuse Treated Sludge: Cost Effective Program Replaces Former Contract with NYOFCo."

53 Sanitation, "Attachment V: Biosolids, Medical Waste and Dredge Spoils Management."

54 Petrillo.

55 National Solid Wastes Management Association, "Municipal Solid Waste Landfill Facts," (2010).



NYC BIOSOLIDS BENEFICIAL REUSE VS. LANDFILL
*Source: NYC EPA 503 Reports

Figure 13:
Between 1998 to 2010, the city was committed to 100% beneficial reuse. By 2012 this had fallen to just 18%, with the rest going to landfill

BIOSOLIDS AS A RESOURCE

NYC biosolid management contracting currently represents a narrow transaction between the city and contractor. Focused on the immediate timeframe, contracting does not consider the larger phosphorus system or long-term trends. While landfilling is currently a least-costly management option, landfill capacity limitations and shifting locations continue to raise the prices of this reuse alternative. At the same time, as we begin to approach peak phosphorus in the future, mining prices will rise. Consequently, the cost of phosphate rock will rise, inflating fertilizer and food prices, and in turn, promoting the value of phosphorus found in biosolids.

LANDFILL

While landfilling currently remains cheaper than beneficial reuse, the era of inexpensive landfill costs may be declining. Currently the number of landfills is shrinking in response to limited space, and in turn escalating prices. According to the EPA, the 7,924 landfills in 1988 were reduced to just 1,908 by 2010, and are continuing to decline. This has led to increases in tipping fees, with annual rates increasing by an average of $1.24 per ton across the US each year.[57] (see: Figure 14 & 15)

Additionally, prices vary by location. Most landfills are found in the west, south, and midwest, with only 128 landfills (7%) in the northeast. This has led to competition and price inflation in the northeast. For example, while Idaho's average landfill tipping fee is approximately $18 per ton, New Hampshire can charge $74 a ton. Whereas NYC previously considered landfills to be the closest, and cheapest, method of disposal, the city and state are now shipping their waste across the nation. NYC biosolids are currently being disposed of in landfills located in Kersey PA, Harrisburg PA, Sussex County VA, and Amsterdam, OH.

Landfilling currently remains a less expensive alternative to beneficial reuse, prompting cities to turn to this course of action in the face of economic downturns. Yet as tipping prices and transportation costs increase, landfilling may no longer be the most cost effective option for biosolid management in the future.[58]

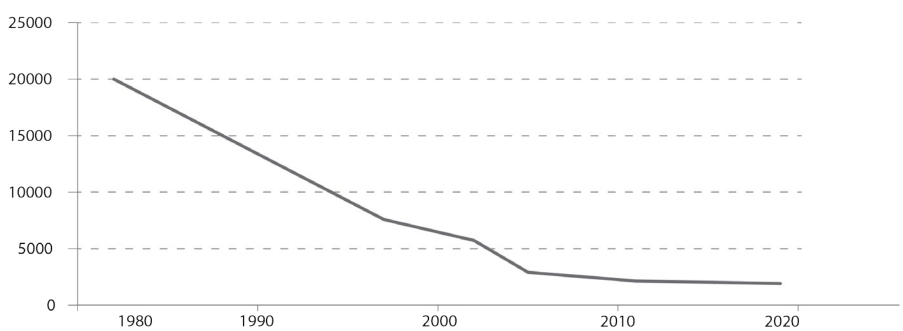
MINING

Landfilling contract costs can also remain artificially low, as they do not take into consideration the larger impact on the phosphorus cycle. Landfilling does not recycle biosolids, eliminating an opportunity for re-use and ensuring future phosphorus demand must be met by mined-phosphates. These mining costs, in part a consequence of biosolid disposal, are not taken into consideration in landfilling costs. While not tied to the physical costs of biosolid management, the rising costs of mining will eventually trickle down, inflating the prices of phosphates, fertilizer, and eventually food. In the future, the rising value of phosphorus

56 Monroe County Division of Solid Waste, "Operation and Maintenance of the Monroe County Recycling Center and Program," ed. Department of Environmental Services (2012).

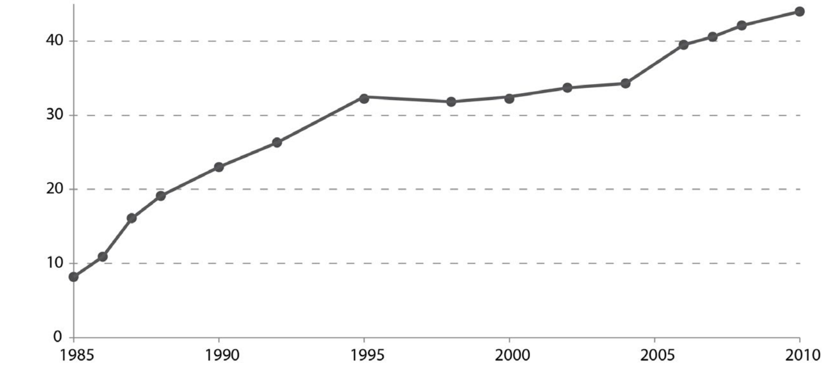
57 "Tipping Fees Vary Across the US," Waste & Recycling News, July 20 2012.

58 Ibid.



US LANDFILL DECLINE
*Source: Waste & Recycling News

Figure 14:
The number of US landfill has been declining since the late 1970s,



US AVERAGE TIPPING FEE
*Source: Waste & Recycling News

Figure 15:
The decreasing number of landfills has led to increases in tipping fees at an average of $1.24 per ton across the US each year. In the future, landfill may not be the least expensive biosolid management alternative

may lead beneficial reuse to be seen as a resource, rather than a cost.

The price of phosphates has steadily, but gradually increased since the 1960s. Currently, the cost of mining phosphorus ranges from $80 to $110 per ton.[59] And these costs will continue to rise. As described by the AFA,

> "…the cost of phosphate rock will increase as lower-cost deposits are mined out and producers have to move more overburden, process lower grade ores, and harness increasingly more expensive technology to produce P concentrates."[60]

As mining prices mount, these costs are reflected in the price of phosphate rocks for fertilizer. This was experienced first hand in 2008 when due to a short-term shortage scare, phosphate prices soared. By June, North African phosphate rock was priced anywhere from $200 to $500 per ton, with a worldwide average of $295 per ton.[61] [62] Today, prices have recovered, with global average phosphate rock prices at approximately $155 per ton (2012).[63]

These costs may seem far from NYC biosolid management. Yet as an input, the rising cost of phosphate rock inflates the price of fertilizer. In 2012, fertilizer prices reached approximately $216 per ton, directly reflecting the rise and fall of phosphate rock prices. These costs subsequently fall to the farmer. During 2012, the US spent approximately $21,000,000,000, or approximately 7% of a farmer's expenses, on fertilizer.[64] Higher fertilizer costs for farmers in turn, are passed onto consumers in the form of higher food prices. This can have major impacts on future food security and international affairs. For example, after the 2008 price spike, China imposed a 135% tax on all phosphate exports.

Current NYC contracts for biosolid landfilling are cheaper than beneficial reuse. Yet this does not look at the economic cycle as a whole. If biosolids are not being recycled, management turns to landfill, which in turn cement our dependence on mined phosphates. The increasing cost of landfills and phosphorus mining may lead to higher fertilizer prices, and consequently, food costs. This also does not include other secondary costs including the $1.68 billion currently being spent on new phosphorus mines, or the approximately $2.2 billion spent by the US to clean up the eutrophication of water bodies.
(see: Figure 16 & 17)

While landfilling is currently a cheaper biosolid management in the immediate market, this represents a short-term transaction without consideration for the longer term, far-reaching consequences. As landfilling and mining costs increase beneficial reuse will allow phosphorus to become a resource for the city.

59 Evans, "Phosphate Resources: Future for 2012 and Beyond."

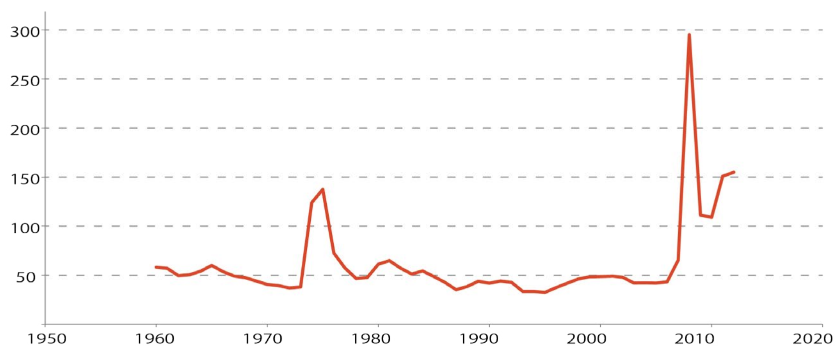
60 IFDC USAID

61 Jasinkski, "Phosphate Rock."

62 World Bank, "Data," (2012).

63 Ibid.

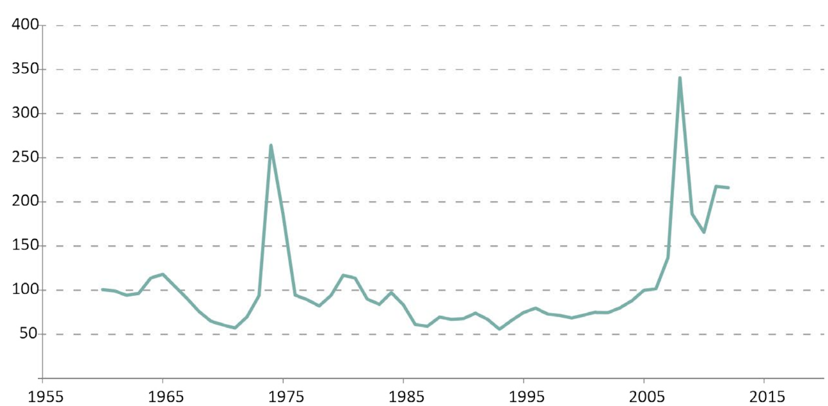
64 NASS



PHOSPHATE ROCK PRICE/TON ($)

*Source: World Bank

Figure 16: As we approach peak phosphorus, increased mining costs will in turn, raise phosphate rock prices



FERTILIZER PRICE/TON ($)

*Source: World Bank

Figure 17: Increasing phosphate prices will transfer into inflated fertilizer prices. These prices are passed onto farmers, and eventually trickle down to consumers in the form of higher food prices.

CONCLUSIONS

As shown, the phosphorus cycle is a comprehensive, systems-based cycle, that when broken can have far reaching effects. The city's biosolid management program does not take into consideration these larger issues at hand. Yet biosolid recycling can be a significant mechanism to re-use phosphorus, closing the cycle and addressing future supply and demand. Ultimately, the city must balance the immediate costs of beneficial reuse with the future costs of a system dependent on landfilling and mining.

By framing biosolids as an alternative to these future scenarios, biosolids can become a resource for the city, rather than a waste. By targeting locations for land application where biosolids are needed and accepted, the city can begin to create a growing demand for NYC waste.

Modifications to the current system can allow NYC to become a model as other cities must also prepare and adapt to the future of phosphorus. While the EPA's part 503 regulations provide technical safety oversight, municipalities have control over the design and operations of biosolid management programs as long as these regulations are met. As NYC had previously committed to 100% beneficial reuse, examining the success and shortcomings of the city's previous biosolid management can become a foundation for future approaches.

In order to frame biosolids as a city resource, NYC can ensure the following ideals are incorporated into their biosolid management: long-term contracting that is less susceptible to short term market fluctuations, application siting that promotes and supports biosolid demand, direct contracting with joint processing and distribution companies, and continued investment into nutrient recovery technologies"

CONTRACT TERMS

After the adoption of the 1990 Management Plan the city immediately entered into three long-term contracts. Over 15 years, the three contracts were responsible for over 70% of the city's beneficial reuse. While supplemented throughout with shorter-term contracts, these three main contracts ensured the city's continued commitment to beneficial reuse.

When the city set up the original contracting strategy that continued for the first 15 years of the biosolid management program, the DEP made a specific note of its decision to employ both short and long-term contracts, explaining the strategy,

> "…provide(d) the stability of a long-term contract with well developed markets and the cost effectiveness of short-term contracts that can respon(d) to emerging market opportunities."

Yet with the 2010 termination of the NYOFCo contract and sequential expiration of the two remaining long-term contracts, the city needed to address the future of biosolid management. Facing an economic downturn, the city entered into five short-term contracts for landfilling, rather than signing a long-term agreement promoting beneficial reuse. It was at this time that the city's beneficial re-use fell to 18%. In short, the city had become too responsive to the market.

In the long term, the rising costs of landfilling and mining may render beneficial reuse the least costly option. However, long-term contracts will ensure the city is committed to beneficial reuse in the interim and well-prepared for system shocks in the future.

SITING

While chosen by the contractor, the DEP monitors and approves of every processing and application site, whether for beneficial reuse or landfilling. The DEP therefore, can encourage land application siting that promotes the demand for beneficial reuse. NYC's previous contract with ParkerAg provides an example of application siting in Prowers County, Colorado, in which NCYC biosolids were accepted and demanded as an alternative to manufactured fertilizer, allowing biosolids to become an opportunity for the city.

ParkerAg, headquartered in Limon, Colorado was one of the first private contractors to begin receiving NYC biosolids. Subcontracted by Synagro, one of the city's original long-term contractors, ParkerAg agreed to distribute approximately 125 wet tons of NYC biosolids per day to local farmers in Prowers County, Colorado. By the time of contract termination in 2010, ParkerAg received over 120,000 dry tons per year,

65 Mike Scharp, "New York City Biosolids Use in Prowers County, CO".

66 Luke Bond.

applied to over 75,000 acres of permitted sites including rangeland, sand dunes, irrigated alfalfa, irrigated corn, and dry land winter wheat. This working relationship allowed NYC to thoughtfully recycle its biosolids to receptive landowners, serving as city guidelines for land application siting that promote a demand for biosolids:[65 66]

LOCATION & ECONOMIES OF SCALE

The contract with ParkerAg applied biosolids to large tracts of agricultural land in Prowers County, Colorado. The county's large-scale agricultural operations resulted in sizable land tracts, with few owners, allowing the city to benefit from economies of scale. Fewer owners on the same acreage of land (for example, as compared to the east coast), still results in the same demand for biosolids, but fewer actual distribution points, allowing for increased distribution efficiency. Additionally, fewer farmers, along with the remoteness of the landscape, increase public acceptance of re-use as neighbors are not disturbed.

CLIMATE & DEMAND

Climate and seasonal variations have molded our current agricultural landscape, and therefore, fertilizer demands. A region's climate defines its growing season, and in turn, fertilizer use. Prowers County, located to the west of the Mississippi, receives anywhere between 11-15 inches of rain per year, allowing for a growing season of approximately 15 of 24 months. Additionally, most farmers employ a cropping pattern in which harvested land is left fallow the following year, requiring nutrients to restore the soil. Almost half of all agricultural acreage, therefore, is available for biosolid application on a daily basis.

In comparison, the east coast growing season runs from approximately April through October, with less need for fertilizer the remaining months. City biosolid production, reversely, does not follow a seasonal cycle. Agricultural land in western states can accept biosolids throughout the year, with less need for storage as required on the eastern coast.

Lastly, climate plays an important role in efficient and safe biosolid application. Soil additives, both manufactured fertilizers and biosolids, contain a ratio of nutrients, nitrogen to phosphorus to potassium. Processed fertilizer usually contains a 10-20-10 ratio, while biosolids usually generate a 4-6-1 ratio of the nutrients. Farmers apply fertilizers or biosolids to meet nitrogen needs, and in the case of biosolid application this often results in excess phosphate application to the soil. As previously explained, excess nutrient runoff, from fertilizers or biosolids, can have severe impacts on local waterbodies. Arid areas like Colorado are less likely to experience this runoff due to low rainfall, allowing for safer biosolid application.

TRANSPORTATION & ACCESS

While Prowers County and other agricultural landscapes in the west provide an ideal site for well-received and environmentally sound application, most, like Prowers County, can be located over 1,000 miles away from the source of the NCY biosolids they are receiving, raising questions about the feasibility of access and distribution. The city originally attempted biosolid transportation through trucking. In 1998, the city entered into a contract with MERCO Joint Venture, agreeing to truck 90 dry tons of biosolids to a ranch in Texas, however, the drive took anywhere from 10-12 days.[67] In response, to bridge the 1,500 miles between Prowers County and NYC, Synagro employed rail. Upon reaching the Colorado station, biosolids were transported no more than 40 miles away to any of the farms. While railroads can often face backups depending on biosolid demand, they ultimately provide a much quicker and safer alternative to trucking.

As distance to landfills grows, biosolid transportation to distant re-use sites is no longer an unreasonable expense. The city in turn, can help direct land application siting to locations with easy and efficient transportation means.

REGULATORY INFRASTRUCTURE & PUBLIC SUPPORT

Most importantly, farmers in Prowers County provided a demand for NYC biosolids. Farmers, already used to applying animal manure, were less suspicious of biosolid application and its processing. ParkerAg and Prowers County also ensured local support by maintaining a transparent process. In 1998, when first approached about biosolid application, the municipality appointed the local health department to oversee operations, in addition to existing state and federal regulations. Local monitoring ensured farmers could trust the biosolid products they were applying to their land.

Cities themselves, along with the companies they contract to, must make the effort to work with local municipalities to ensure application safety and acceptance.

Ultimately, land, climate, and transportation characteristics will vary between locations, with those listed unique to Prowers County, Colorado. While these siting recommendations work specifically in the United States, siting specifications should be adapted and specialized to each location, with the ultimate goal of promoting demand, and in turn, supporting biosolids as a resource or opportunity for cities.

67 Federation Water Environment and US EPA, "Biosolids Recyling in West Texas: Biosolids Fact Sheet," (2000).

68 Petrillo.

69 http://www.ostara.com

DIRECT CONTRACTING

By 2005, ParkerAg was responsible not only for the distribution, but also the processing of biosolids. In 1998, the beginning of the ParkerAg contract, farmers received Class A biosolids, higher quality material that was shipped from NYC and directly applied to the land. Class A biosolids, however, required much monitoring and risk, as one flaw required the entire month's batch to be discarded.[68]To replace the Class A biosolids, ParkerAg became responsible for treating biosolids with alkaline, or lime, to ensure safety regulations were met. Yet while responsible for both processing and distribution, ParkerAg was still under contract with Synagro. As the city ended its beneficial reuse contracts with Synagro (NYOFCo and EPIC), the city also ended its relationship with ParkerAg.

In the future, cities should enter into direct contracts with companies that can process biosolids at distribution sites. Combining processing and distribution contracts eliminates the need for a middle agent, shortening the path between urban sources and biosolid application, and thereby reducing costs.

TECHNOLOGY

Lastly, to ensure biosolids become a resource, NYC must continue to invest in new nutrient recovery technologies. By encouraging research and pilot projects, the city can improve extraction techniques, reducing costs and encouraging future biosolid use.

Ultimately, in most cities, waste streams contain more than just human waste, combining household waste and in some cases, storm water, diluting nutrient content and hindering biosolid processing. Many cities have already begun to invest in technologies to divert human wastes from the remaining waste stream. Ultimately, New York City's combined sewer system, in which all household, human waste, and storm water enter wastewater treatment plants in one stream make waste diversion a long-term goal. However, the city can begin to experiment with technologies that allow for easier removal of phosphorus and other nutrients. For example, emerging companies have promised revolutionary technologies that remove phosphorus in wastewater streams. Ostara, headquartered in Vancouver, has invented technology that removes nutrient build-up in pipes, extracting 90% of phosphorus that in turn is processed into a commercial fertilizer, Crystal Green69

While Ostara is just one example, new technologies can help artificially restore the natural phosphorus cycle and improve biosolid processes. In turn, efficient nutrient recovery allows biosolids to become a future resource for the city.

CONCLUSION

Most importantly, the city must first and foremost, recognize and begin to address the future of phosphorus. As we enter a new stage in which mined phosphorus supply, in either quantity or price, may not be able meet growing demand, biosolids provide a means to relink the form of resource recovery. As we face a future phosphorus shortage, biosolids represent a way to relink the phosphorus cycle, becoming a form of phosphorus supply that can become an opportunity for cities. Ultimately, cities therefore must frame biosolids as a resource; incorporating beneficial reuse into biosolid management plans. To ensure continued reuse, cities must promote biosolid demand by ensuring long term contracting, specifying land application siting, direct contracting, and investing in new technologies.

While these recommendations specifically revolve around NYC, the ideals can be extracted to cities across the globe as we continue to turn to biosolids as a form of phosphorus recovery. While biosolid beneficial reuse cannot meet the full extent of our global phosphorus demands, biosolid management and the continued reuse of waste can prepare against future shortages as part of a larger solution. [37]

BIBLIOGRAPHY

Area, Gateway National Recreation, and Jamaica Bay Watershed Protection Plan Advisory Committee. "An Update on the Disappearing Salt Marshes of Jamaica Bay, New York." edited by U.S. Department of the Interior, 2007.

Ashley, K., D. Cordell, and D. Mavinic. "A Brief History of Phosphorus: From the Philosopher's Stone to Nutrient Recovery and Reuse." Chemospher 84 (2011): 737-46.

Association, International Fertilizer Industry. "Florida Phosphate Mining." http://cenvironment.blogspot.com/2010/11/florida-phosphate-mining.html.

Association, National Solid Wastes Management. "Municipal Solid Waste Landfill Facts." 2010.

Association, North East Biosolids and Residuals. "Offical Usage of the Term "Biosolids"." 2008.

Bank, World. "Data." 2012.

Biosolids Management, Bureau of Wastewater Treatment. "Us Epa 40 Cfr Part 503: Use or Disposal of Sewage Sludge 2007 Annual Report." NYC Department of Environmental Protection, 2008.

Cooper, Keith R., and Marija Borjan. "Northeast Coastal and Barrier Network Assessment of Contaiminant Threats." edited by U.S. Department of the Interior. Colorado: National Park Service, 2010.

Cordell, D., A. Rosemarin, Schroder J.J, and A.L. Smit. "Towards Global Phosphorus Security: A Systems Framework for Phosphorus Recovery and Reuse Options." Chemosphere 84 (2011): 747-58.

Cordell, Dana, Jan Olof Drangert, and Stuart White. "The Story of Phosphorus: Global Food Security and Food for Thought." Global Environmental Change 19 (2009): 292-305

El-Shall, Dr. H., Dr. R. Stana, A. El-Midany, and S. Malekzadah. "In-Situ Mining of Phosphate Ores." Department of Materials Science and Engineering

University of Florida 2004.

Elser, James, and Suart White. "Peak Phosphorus, and Why It Matters." Foreign Policy (2010).

Evans, Mark. "Phosphate Resources: Future for 2012 and Beyond." Paper presented at the 18th AFA International Annual Fertilizer Forum & Exhibition, Sharm El-Sheikh, Egypt, 2012.

Hartig, Ellen, Vivien Gornitz, Alexander Kolker, Frederick Mushacke, and David Fallon. "Anthropogenic and Climate Change Impacts on Salt Marshes of Jamaica Bay, New York City." Wetlands 22, no. 1 (2002): 71-89.

Ippolito, Jim, and Bob Brobst. "The Science of Biosolid Land Application." 2012.

Jasinkski, Stephen. "Phosphate Rock." In Mineral Commodity Summaries: US Geological Survey, 2012.

Jason Flury, WeCare Organics. Interview, Feburary 8 2013.

Luke Bond, ParkerAg Compliance Manager. Interview, February 7 2013 2012.

Metson, Genevieve, Elena Bennett, and James Elser. "The Role of Diet in Phosphorus Demand." IOP Science 7, no. 4 (2012).

New York- New Jersey Harbor & Estuary Program. "The State of the Estuary 2012: Environmental Health and Trends of the New York-New Jersey Harbor Estuary ".

O'Shea, Marie L., and Thomas M. Brosnan. "Trend in Indicators of Eutrophication in Western Long Island Sound and the Hudson Raritan Estuary." Estuaries 23, no. 6 (2000): 877-901.

Parker Ag Services, LLC. "Services." http://www.parkerag.com/Profile/About.htm.

Petrillo, Beth. 2012.

"Phosphorus." In Cambridge World History of Food, edited by Kenneth F. Kiple and Kriemhild Conee Ornelas. 834-43. Cambridge, United Kingdom: Cambridge University Press, 2000.

Programme, United Nations Environment. "Phosphorus and Food Production." In UNEP Yearbook 2011: United Nations 2011.

Programme, United Nations Environment, and International Fertilizer Industry Association. "Environmental Aspects of Phosphate and Potash Mining." 2001.

Protection, NYC Department of Environmental. "New York City's Wastwater Treatment System."

Rhoads, John M., David J. Yozzo, Marco M. Cianciola]Barry A. Vittor, and Robert J. Will. "Noton Basin/Little Bay Restoration Project: Historical and Environmental Background Report." New York: U.S. Army Corp of Engineers, 2001.

Sanitation, NYC Department of. "Attachment V: Biosolids, Medical Waste and Dredge Spoils Management." In Solid Waste Management Plan, 2004.

———. "Attachment V: Biosolids, Medical Waste, and Dredge Spoils Management." In Solid Waste Management Plan, 2006.

Scharp, Mike. "New York City Biosolids Use in Prowers County, Co."

Sklerov, Farrell, and Angel Roman. "Dep Issues Request for Proposals to Resuse Sludge: Seeks Cost-Effective, Sustainable Program to Use Treated Sewage in Beneficial Way." edited by NYC Department of Environmental Protection. New York, 2010.

Sklerov, Rarrel, and Angel Roman. "Dep Selects Vendor to Beneficially Reuse Treated Sludge: Cost Effective Program Replaces Former Contract with Nyofco." edited by NYC Department of Environmental Protection. New York, 2011.

State, New York. "Biosolids Management in New York State." edited by Department of Environmental Conservation: Division of Materials Management. Albany, NY, 2011.

———. "New York State Law Restricts Use of Lawn Fertilizers Beginning January 1, 2012." edited by Department of Environmental Conservation. New York, 2012.

"Tipping Fees Vary across the Us." Waste & Recycling News, July 20 2012.

USDA. "National Agricultural Statistics Service", 2012.

Vaccari, David. "Phosphorus Famine: The Threat to Our Food Supply." Scientific American (2009).

Walker, John, Lynn Knight, and Linda Stein. "A Plain English Guide to the Epa Part 503 Biosolids Rule." edited by US EPA Office of Wastewater Management. Washington, DC, 1994.

Waste, Monroe County Division of Solid. "Operation and Maintenance of the Monroe County Recycling Center and Program." edited by Department of Environmental Services, 2012.

Water Environment, Federation, and US EPA. "Biosolids Recyling in West Texas: Biosolids Fact Sheet." 2000.

World Environmental and Water Resources Congress 2010: Challenges of Change. Edited by Richard N. Palmer: American Society of Civil Engineers, 2010.

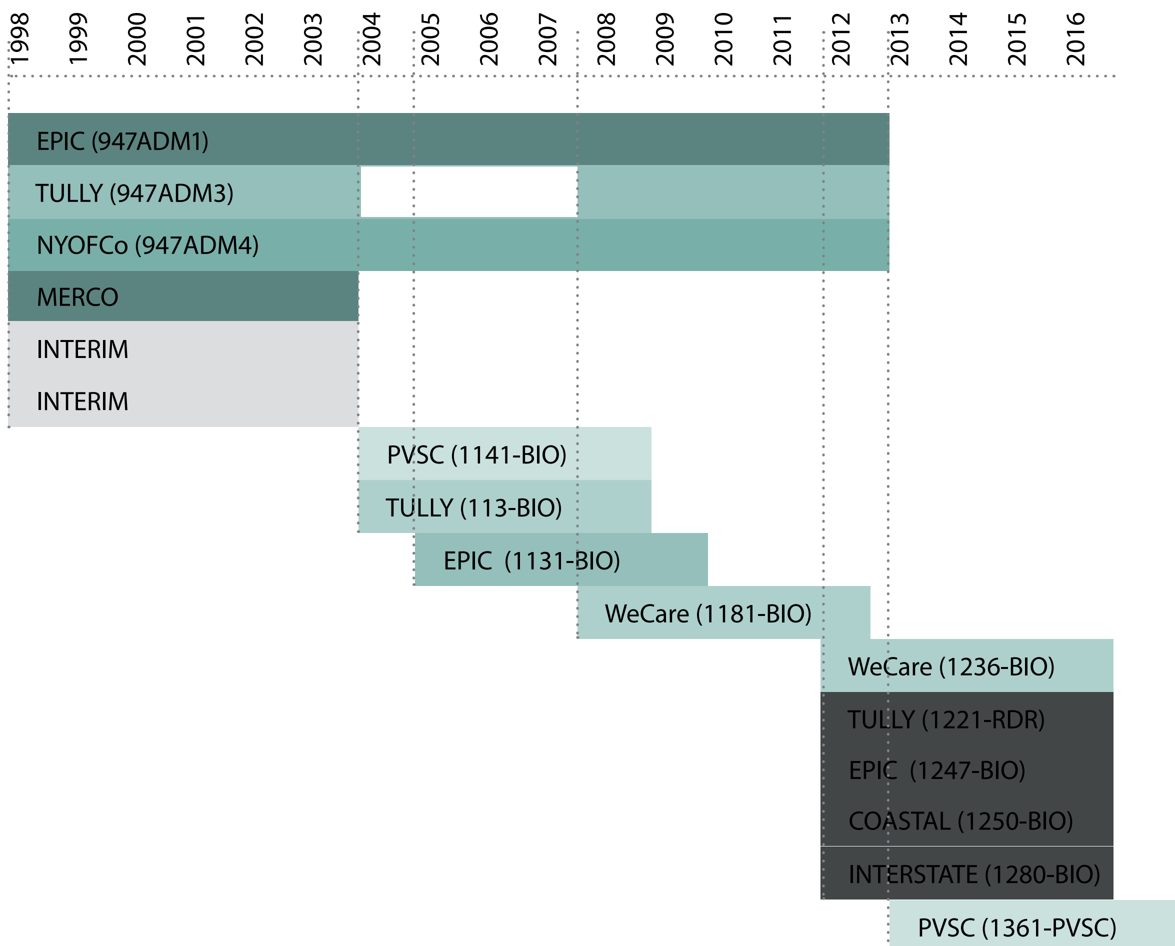
APPENDIX A

NYC BIOSOLID CONTRACTING DATA & BACKGROUND

As part of the 1990 Sludge Management Plan, the city began a new approach towards sludge disposal. In addition to the three long-term, 15-year contracts, the city relied on rotating, short term contracts to manage the 1,200 tons of sludge produced per day. Together accounting for approximately 13 contracts between 1998 and 2013, the long and short term contracts utilize a mix of beneficial reuse and landfilling as described below.

The following information was gathered from NYC annual 503 Reports to the EPA:

TIMELINE:



PRICES

CONTRACT		PROCESSING	CONTRACT COST	BIOSOLID ALLOCATION		PRICE RANGE (PER TON)	
EPIC	947ADM1	Direct Application	$14,000,000	225	510	$173	$75
NYOFCO	947ADM4	Thermal Drying	$32,000,000	510	825	$174	$106
TULLY	947ADM3	Alkaline Treatment	$2,900,000	100	200	$81	$40
TULLY	1113-BIO	Composting	$3,400,000	75	150	$126	$62
"EPIC	21131-BIO	Alkaline Treatment	$7,900,000	150	300	$146	$72

*Price per ton was calculated by determining the minimum and maximum biosolid allocation per contract, and dividing by contract cost to determine a range of high to low price per ton.

1998-2003

In addition to the three long-term contracts, after the initiation of the Management Plan, the city entered into three, 5-year interim contracts that contributed to the city's commitment to 100% beneficial reuse.
*information was only available on the following agreement:

1. MERCO JOINT VENTURE (MERCO), 5 YEAR CONTRACT ENTER JUNE 1998

Entered into with MERCO Joint Venture, a private consortium located in Freeport, NY, the agreement trucked 80 dry tons of NYC biosolids10-12 days to the Sierra Blanca Ranch in Hudspeth County, Texas. Aiming to re-vegetate arid and semi-arid rangeland, three dry tons of biosolids were applied to 40 acre plots daily. Tested both in New York and Texas, the biosolids increased filtration and decreased erosion, increased native grass production, and generated higher levels of plant available nutrients.[1]

2004-2006

As the original interim contracts came to an end, the city entered into new three-year contracts, remaining committed to 100% beneficial reuse:

1. TULLY AND HYDROPRESS ENVIRONMENTAL SERVICES, INC (TULLY 1113-BIO) 3 YEAR CONTRACT, EXPIRATION 2007 (1 YR RENEWAL OPTION)

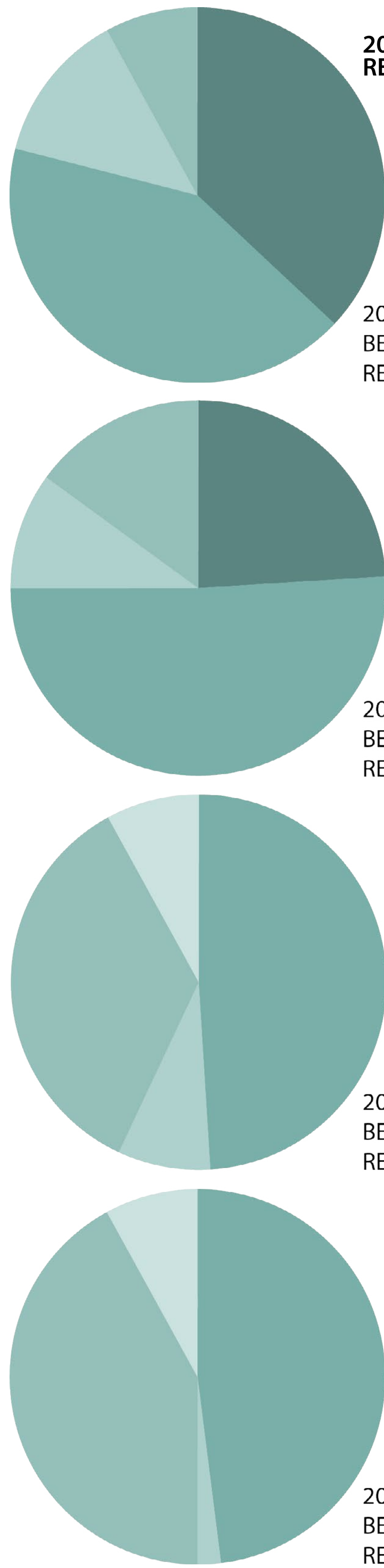
Entering into a second contract with the city in 2004, Tully was responsible for trucking between 75-150 wet tons per day of sludge to their Natural Soils Products Facility in Good Springs, Pennslyvania. Composting the sludge, the resulting mulch-like product was applied golf courses, nurseries, lawns etc. The contract specified up to 10% of the compost could be requested by, and returned to, the city for community projects, eventually being used as Port Richmond, Tallman Island, Queens Botantical Gardens, and Randall's Island Sports Complex.

Over the three year contract, with a one year renewal option, Tully was responsible for composting approximately 7% of the city's sludge.[234]

2. R.J LONGON CONSTRUCTION, ENVIRONMENTAL PROTECTION AND IMPROVEMENT CONTROL EPIC 2 (1131-BIO) ENTERED INTO 2005 3 YEAR CONTRACT (1 YR RENEWAL OPTION)

Entering into a second contract with EPIC, owned by Synagro, the three year contractor was responsible for the alkaline treatment of 150 to 300 wet tons daily.

Combining with the existing Tully 15-year contruact, alkaline treatment accounted for approximately 24% of the city's biosolid management.



1 Federation Water Environment and US EPA, "Biosolids Recyling in West Texas: Biosolids Fact Sheet," (2000).

2 NYC Department of Sanitation, "Attachment V: Biosolids, Medical Waste, and Dredge Spoils Management," in *Solid Waste Management Plan* (2006).

3 "Attachment V: Biosolids, Medical Waste and Dredge Spoils Management," in *Solid Waste Management Plan* (2004).

4 Bureau of Wastewater Treatment Biosolids Management, "US EPA 40 CFR Part 503: Use or Disposal of Sewage Sludge 2007 Annual Report," (NYC Department of Environmental Protection, 2008).

3. PASSAIC VALLEY SEWERAGE COMMISSION
PVSC (1141-BIO)

In 2004, NYC DEP also entered into an inter-governmental agreement with Passaic Valley Sewerage Commission after the Oakwood Beach dewatering facility shut down in October 2005 for repairs. The contract allowed for the hauling of liquid sludge from Oakwood Beach, Port Richmond, and Owls Head wastewater treatment plants (and later expanded to include all NYC facilities), to the PVSC Newark, NJ plant. While the Oakwood facility was out of service until August 2006, the agreement was extended until December 2008 to provide additional facility to NYC facilities. All NYC liquid sludge dewatered at the PVSC facility was sent to the NJ Meadowlands Commission. While the specifics of the land application are unclear, it is described by the 2006 503 Report as "beneficial"

PVSC also provided support as Tully Environmental asked for a suspension on their original 15 year contract in February 2004 due to internal reorganization.

2007-2008

By 2007, the city's three long-term agreements were still underway:

EPIC 1:

The city continued to send approximately 20% of its biosolids to the EPIC 1 contract for land application in Colorado and Alabama.

TULLY:

In July 2007, the original 15-year Tully Environmental contract was also resumed after the three year suspension, and approximately 12% of the city's biosolids were again used for mine reclamation in Pennsylvania after alkaline stabilization.

NYOFCO:

Approximately 29% of the city biosolids continued to be thermally dried in the Bronx, meeting the "exceptional Quality Sludge Criteria." Application of the pellets, however, shifted: cattle, citrus Groves, and pine trees in Colorado, feed crops (corn & sod) in New Jersey, and pine trees in Georgia. Additionally, over 1,035 tons were sent to Oman, UA for desert reclamation and landscaping, along with feed crops including beans, squash and cucumbers.

Additionally, as the Tully contract (1113-BIO) terminated on October 31, 2007 a new contract was implemented beginning December 17, 2007 with WeCareOrganics:

1. WECARE ORGANICS
WECARE (1181-BIO), 3 YEAR CONTRACT, EXPECTED EXPIRATION 2009

WeCare Organics, owned by Tully Environmental, was contracted beginning in 2007 to process approximately 8% of the city's bisolids for beneficial reuse. Composting the biosolids, WeCare organics sold the soil amendment to athletic fields, golf courses, parks, and topsoil manufacturers who use the compost to increase organic matter in soil.

2009-2012

As mentioned above, by 2010 the NYOFCo contract had been terminated by the city. Additionally, the city faced the upcoming of the remaining two long term contracts, along with the expiration of the Tully (1112-BIO), EPIC 2 (1131-BIO), and PSVC (1141) short term three year contracts.

In turn, by 2012 (according to the 2012 503 report) the city had entered into 4 new contracts which reduced beneficial reuse in the face of the city's economic downturn (see above):

1. TULLY ENVIRONMENTAL
TULLY (1221-RDR)

A supplemental contract, the agreement holds Tully responsible for transportation and disposal on a as-need basis to landfills in Kersey and Harrisburg, PA. In 2012, this accounted for only 21.65 tons of sludge, a negligible percentage

2. ENVIRONMENTAL PROTECTION & IMPROVEMENT COMPANY
EPIC 3 (1247-BIO)

While the previous 2 contracts entered into with EPIC both stipulated the beneficial reuse of NYC biosolids, this agreement calls for the transportation and disposal at the Atlantic Waste Disposal landfill in Sussex County, Virginia. In 2012, this contract was responsible for 23,901 dry metric tons of sludge, or approximately 24%.

3. COASTAL DISTRIBUTION
COASTAL (1250-BIO)

Coastal is in contract with the NYC DEP for the transportation and disposal of biosolids to landfill. Originally contracted to dispose at the Brookville Landfill in Brookhaven, NY, the landfill was ordered to stop accepting biosolid material by the NYSDEC in March 2011. Coastal now contracts disposal to EPIC, which is then disposed of in Sussex County, Virginia. In 2012, Coastal was responsible for the disposal of approximately 28,236 dry metric tons, or 29% of the city's biosolids.

4. INTERSTATE WASTE SERVICES
INTERSTATION (1280-BIO)

NYC DEP's contract with Interstate allocates the transportation and disposal services for biosolids at the landfills located in Amsterdam, Ohio. In 2012 Interstate was responsible for 28,326 dry metric tons, or 29% of NYC biosolids
By 2012, beneficial reuse had fallen to just 18%.