July 2014

AIRPORT COOPERATIVE RESEARCH PROGRAM
Sponsored by the Federal Aviation Administration

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Research Results Digest 21

BEST PRACTICES FOR GENERAL AVIATION AIRCRAFT FUEL-TANK SAMPLING

This report presents the results of ACRP Project 11-02, Task 22, "Best Practices for General Aviation Aircraft Fuel-Tank Sampling." The research was conducted by a team lead by Hagerty Environmental, LLC. The Digest summarizes the research and presents several best practices for general aviation fuel-tank sampling. The Principal Investigator (PI) for this research project was Paul Hagerty. Contribution to the research and review process was provided by Carmine Balascio, University of Delaware, and Jonathan Martin, New Garden Township, Pennsylvania.

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INTRODUCTION

As part of a typical general aviation (GA) internal combustion engine preflight inspection, the pilot normally takes fuel samples from fuel system drains (a.k.a. "sumps") and visually inspects them for color and contamination (e.g., water, particulate). Although these fuel samples can be returned to the fuel tank if they are uncontaminated, or disposed of in an approved container if contamination is found, it is generally acknowledged that many pilots simply discard the fuel samples to the ground surface regardless of whether contamination was identified or not. This disposal practice is inconsistent with many airport pollution prevention procedures and environmental regulations and can lead to stormwater runoff contamination and air pollution.

The Airport Cooperative Research Program (ACRP) commissioned this project to evaluate this disposal practice, and specifically, to accomplish the following two objectives:

- **Objective 1**—Estimate the discard amounts from fuel testing samples that are entering the stormwater runoff system.
- **Objective 2**—Develop a variety of airport and aviation best practices of aircraft fuel-tank sampling to prevent contaminants from entering the stormwater runoff system.

Objective 1 was accomplished by conducting pilot surveys, field-based research, and mathematical calculations and Objective 2 was accomplished by performing literature reviews, inquiries and field testing, and preparing this Digest.

Given that the best practices presented in this Digest are aviation-based, the intended audience for this document is GA pilots, airport managers, flight schools, and other aviation personnel and organizations. These entities have a role or vested interest in (a) proper fuel management and disposal and (b) the potential consequences if not these are not conducted properly.

OBJECTIVE 1—QUANTITY ESTIMATE

The Objective 1 quantity estimate was accomplished by collecting raw data from pilot surveys and field-based observations, applying various assumptions, and conducting mathematical calculations to

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arrive at the estimate. The following sections provide an overview of the process and the resulting quantity estimate.

Data Collection Methodology

Data were collected by conducting an electronic survey of pilots' typical disposal practices (*1*). The survey was disseminated via various aviation networks (e.g., Facebook, LinkedIn, Aircraft Owners and Pilots Association [AOPA] website forum, pilot-based email lists) and consisted of the following 11 questions:

1. *Do you currently pilot an aircraft with a reciprocating (i.e., piston) engine?*
2. *How many fuel system sample locations (a.k.a. sumps) does the primary aircraft you fly have (including cowl drains, gascolators, etc.)?*
3. *Does the primary aircraft you fly have a sump/strainer location which is remotely operated (e.g., inside the top of cowl or in cockpit) that makes sample collection difficult or impractical?*
4. *Select the response below which best describes your "typical" fuel sampling/sumping procedures?*
5. *When collecting fuel samples for visual inspection, what type of fuel sampling device do you primarily use?*
6. *When collecting fuel samples for visual inspection, how much of a sample do you normally collect from each sump location?*
7. *What do you do with the fuel sample(s) once they have been collected and inspected?*
8. *How often have you experienced significant contamination in your fuel samples (e.g., water, excess particulate, etc.)?*
9. *Where did you learn your current fuel testing/sumping procedures?*
10. *When did you receive your primary flight training?*
11. *How many hours of flying do you average per year (reciprocating only)?*

The survey was available for 1 month from September 16 through October 16, 2013. It was completed by 146 respondents. The size of this dataset was considered adequate for two reasons. First, the PI periodically reviewed the survey data over the 1-month survey period and noted that the responses were fairly consistent at the onset of the survey as compared with the survey close date. Second, field-based research was conducted at three GA airports (discussed in the Current State of the Practice section) and corroborated the range and general distribution of the responses from the pilot survey. As an example of the range of disposal behaviors received from the survey, Figure 1 presents a graphical summary of the responses from survey question 7.

Calculation Methodology

Generally speaking, the fuel discard estimation was carried out by multiplying the average fuel disposal quantity per flight (from the survey data) by the

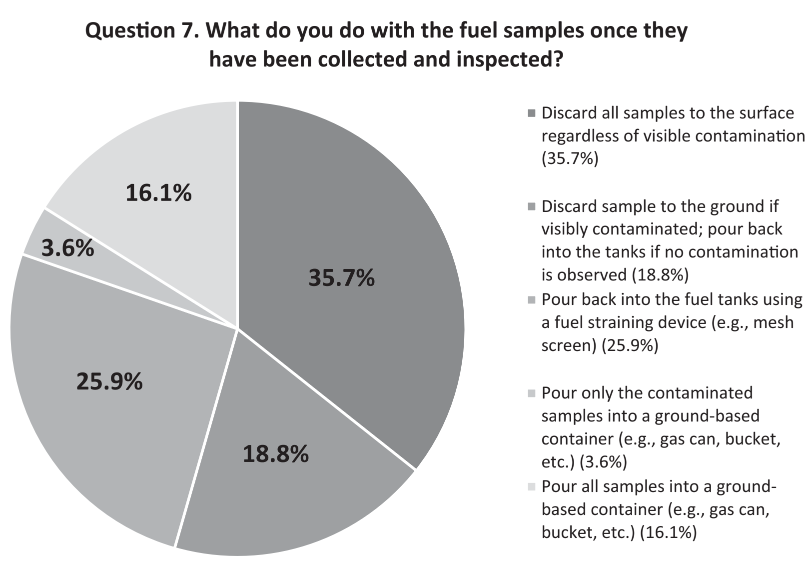

Figure 1 Data summary from survey question 7.

number of GA operations per year (from Federal Aviation Administration [FAA] database) (*2*). Numerous assumptions were made to adjust the survey data and the FAA database data. These assumptions and adjustments are summarized below.

- **Step 1**—Average sump locations per aircraft (from survey results)—3.479 **("A").**
- **Step 2**—Average quantity of a *full* sump sample (takes into account the respondents' specific type of samplers used)—42.595 milliliters (mL) **("B").**
- **Step 3**—Adjusted per-sample quantity based on how full the average pilot fills the sampler (~45% full)—0.45 × B = 19.306 mL **("C").**
- **Step 4**—Average sample quantity per flight—A × C = 67.166 mL **("D").**
- **Step 5**—Adjust per-flight quantity based on the following:
  - **Step 5A**—Reduce based on pilots disposal habits of returning sample to fuel tanks or placing in disposal containers—0.368 **("E").**
  - **Step 5B**—Increase based on weighted average of some aircraft that have a remote sump location which cannot be collected—5.36 mL per flight **("F").**
- **Average Per-Flight Discard**—(D × E) + F = 30.1 mL per flight **("G").**

FAA data (*2*) were reviewed for GA operations in the United States to determine the total number of GA operations per year. This number was then reduced in a stepwise fashion for various known factors as summarized below.

- **Step 6**—Start with raw "operations" data (81,529,543 operations) and apply a series of reduction factors as follows:
  - Apply 0.5 factor since operations data include take-offs and landings.
  - Apply 0.5 factor since many take-offs are touch-and-goes for flight training, which do not result in a sumping/sampling event (see Conclusions and Suggestions section for sensitivity analysis).
  - Apply factor from survey (0.811) to account for pilots who either do not sump upon refueling or do not sump before flight.
  - Apply factor from FAA data (0.948) for those GA operations that are jet engines.
  - Total annual GA operations which result in fuel sample discard to ground = 15,680,190.
- **Step 7**—Estimate the total quantity of fuel discarded to the ground surface.
  - Adjusted per-aircraft sump quantity times adjusted annual GA operations = 471,882,554 mL.
  - Converted to gallons ➔ *124,672 gallons per year.*

Quantity Estimate

Based on the survey data, FAA data, field data, and assumptions presented herein, the total estimated quantity of fuel discarded to the ground surface annually from GA operations is approximately 125,000 gallons. Note that a majority of the input variables can be substantiated with data, observations, or supported assumptions, except the reduction factor for touch-and-goes (Step 6 bullet point 2, currently 0.5). If low- and high-range reduction factors are applied for a sensitivity analysis (low = 0.3 and high = 0.7), the estimated range of fuel discarded to the ground annually by GA operations is **75,000 gallons to 175,000 gallons.**

It should be noted that the objective of the research was to estimate the discard amount *that enters the stormwater runoff system* from airports. It has long been argued or rationalized by pilots that discarded fuel will evaporate and thus not negatively impact the environment. The various fate and transport mechanisms for discarded fuel are discussed in the Discarded Fuel—Fate, Environmental Implications, and Applicable Regulations section. It should also be noted that the estimate provided in this Digest is the average quantity discarded to the ground surface, and not necessarily the quantity that enters the stormwater system. Determining the quantity of discarded fuel that actually enters the stormwater system would require extensive stormwater sampling, monitoring, and modeling, all of which are beyond the scope of this research project.

Previous Estimates and Quantity in Context

An estimate of 3 million gallons of aviation fuel discarded to the ground surface annually was found in the literature during the research (*3*). Although the objectives of the research project did not include evaluating or checking previous estimates, the 3-million gallon estimate is quite inconsistent with the value identified herein, and was hence given a cursory review. The 3-million gallon value appears to be overestimated for the following reasons:

- **Overestimate of Sump Quantity**—A per-flight sump quantity of 8.5 liquid ounces, or about 250 mL, was used. This is over eight times greater than the amount estimated in the current research (G = 30.1 mL).
- **No Reductions for Disposal Behavior—**No reductions were incorporated for pilots who may take smaller samples, who may return the fuel to the fuel tanks, or who may not conduct a pre-flight sampling exercise, all of which were confirmed in the current research.
- **Not All Take-offs Involve Sampling—**No reductions were incorporated for the fact that not all take-off operations involve a sampling event.
- **Not Plausible—**Three million gallons is nearly 1% of the total aviation gasoline (avgas) consumed (377,000,000 gallons), as referenced in the calculation itself. As an example of implausibility, each average single engine GA aircraft refueling exercise (~50 gallons) would result in nearly one-half gallon discarded. This is not plausible and is inconsistent with the field research conducted as part of this research project.

The estimated quantity of between 75,000 gallons and 175,000 gallons per year can be put into context with other petroleum discharge estimates such as the following:

- 2.6 million gallons of oil is spilled per year, which impacts navigable U.S. waterways (*4*).
- 16 million gallons of petroleum per year are released to the sea via stormwater runoff and rivers (*5*).
- 17 million gallons of gasoline are spilled each year by overfilling lawn mowers (*6*).
- 11 million gallons of oil were released by Exxon Valdez (*7*).
- Over 200 million gallons of oil were released by the Deepwater Horizon incident (*8*).
- 100 million gallons of oil are spilled each year in the United States (*9*).
- The EPA asserts that 200,000,000 gallons of used oil are improperly disposed of annually (*10*).

To put the research quantity estimate into further context, consider that there are currently 5,295 public use landing facilities (i.e., airports) in the United States (J. Collins, email communication, December 31, 2013). If an assumption is made that the quantity of discarded fuel is equally divided among these public use landing facilities, this amounts to between 14 and 33 gallons discarded per airport per year.

OBJECTIVE 1—SYNOPSIS
Quantity Estimate

The estimated range of fuel discarded to the ground annually by GA operations is 75,000 gallons to 175,000 gallons. This amounts to between 14 and 33 gallons discarded per airport per year.

DISCARDED FUEL—FATE, ENVIRONMENTAL IMPLICATIONS, AND APPLICABLE REGULATIONS

Sampled fuel that is discarded to the ground surface can interact and move in the environment in a number of ways. These interactions and movements are often called "fate and transport" mechanism. These mechanisms, along with key environmental impacts and applicable legal implications, are discussed in the following sections.

For an appropriate fate and transport discussion, it is important to have a general understanding of avgas. Avgas can consist of over 150 chemicals, all of which behave differently in the environment once discarded. Avgas consists almost exclusively of compounds formed by hydrogen and carbon molecules, and is hence considered a petroleum "hydrocarbon." Avgas also consists of a minor amount of inorganics, most specifically lead, in the form of tetraethyl lead (TEL). The lead raises the octane, prevents engine knock, and prevents valve seating issues. The most commonly used form of avgas for GA, 100 octane low lead (100LL), can contain up to 2.12 grams of lead per gallon (*11*). Petroleum hydrocarbons in avgas behave quite differently depending on the complexity of their individual chemical structures. The lighter hydrocarbons are more volatile (evaporative) while the heavier, oilier constituents are less volatile and more persistent in the terrestrial environment. The lead can also persist in the terrestrial environment.

Primary Fate and Transport Mechanisms

Once discarded to the ground surface, avgas can degrade, persist, or move in the environment in a number of ways. The primary fate and transport mechanisms are summarized below:

Evaporation/Volatilization. This mechanism accounts for a majority of fuel loss upon surface discard; however, pilots should be aware that the discarded fuel does not simply disappear. Rather, the fuel is simply converted from the liquid phase to the vapor phase, where it can become an air pollutant. Volatilization rates are highly dependent on numerous factors, including temperature, pressure, atmospheric moisture, and fuel-specific characteristics. It is estimated that as much as 95% of petroleum can be lost to volatilization within hours of discharge (*5*). Volatilization as a method of dealing with discarded avgas is inconsistent with other similar industries (e.g., vehicle refueling stations, vehicle manufacturers) which are required by the 1990 Amendments to the Clean Air Act (CAA) to install various vapor recovery systems to control volatile organic compound (VOC) emissions from vehicle refueling and tank refilling operations. The dispensing facilities alone are estimated to spend over $88 million annually in the operation of Stage II vapor recovery systems (ESIS, Inc., unpublished white paper, October 2013).

Degradation. The constituents of avgas that do not evaporate are left behind to persist in the environment. Based on numerous factors, this remaining mass may degrade by any number of physical, chemical, or biological processes. One such process which has been successfully employed for remediation of petroleum hydro-carbon is biodegradation, or degradation mediated by microorganisms. Biodegradation requires optimum environmental conditions for the complete degradation of petroleum hydrocarbons to harmless byproducts (e.g., CO_2, H_2O). These environmental conditions include the presence of the appropriate type of indigenous microorganisms, temperature, moisture, oxygen, and nutrients. Biodegradation is a relatively slow process (e.g., months, years) and is not believed to be an adequate response to discarded fuel based on the rates and reliance on optimum conditions. It should be noted that, although lead is an inorganic and inorganics are generally not biologically degradable, some research has shown that TEL, which has an organic component, can be biologically degraded (*12*). Compounds that do not degrade are left to persist in the environment until a transport mechanism carries them away as discussed below.

Infiltration. Infiltration occurs when avgas is transported vertically downward, either by its own gravitational forces or by the driving force of precipitation. Infiltration is generally limited to permeable surfaces (e.g., grass tie-downs). However, aviation fuel can chemically soften the asphalt binder material of paved areas and degrade the asphalt itself, creating localized permeable areas at permanent tie-downs (*13*). This localized permeability can then lead to transport (infiltration) of petroleum hydrocarbons to the underlying soil and groundwater.

Stormwater. Avgas residuals that are not evaporated, degraded, or transported to the subsurface remain available for transport via stormwater runoff. Transport can occur by dissolving the lighter fractions of the fuel within the stormwater or by physically transporting the heavier and particulate fractions with the stormwater flow. Depending on the stormwater management features of the airport, this hydrocarbon-containing stormwater can be temporarily detained in stormwater management features (e.g., basins, treatment wetlands), can be carried to permeable areas for infiltration, or can be transported to adjacent streams, lakes, wetlands, or other similar receiving water bodies.

Environmental Implications

Petroleum hydrocarbons in stormwater runoff, even at low concentrations, are known for their acute toxicity to aquatic organisms in receiving streams (*14*). At even lower concentrations where acute toxicity might not be immediately evident, research has shown long-term impacts to aquatic organisms (*15*). Metals in urban stormwater have the potential to impact water supplies and cause acute or chronic toxic impacts for aquatic life (*14*). Despite evidence of ecosystem consequences resulting from stormwater runoff, identifying human health impacts from stormwater runoff are not yet possible (*15*).

Applicable Laws and Regulations

Laws and regulations that may govern GA fuel sampling and disposal practices can come from the federal, state, and/or local level and can be quite complex and subject to interpretation. The following sections provide an overview of potentially applicable regulations and how they may impact GA fuel sampling practices. However, it should be noted that this Digest does not provide a full legal review and GA pilots are advised to independently review any and all applicable laws and regulations.

Federal regulations. The most applicable federal laws and regulations regarding GA fuel-tank sample disposal are likely the CAA and the Clean Water Act (CWA), both of which are implemented by the U.S. Environmental Protection Agency (EPA), although both are more locally administered and enforced by the individual states. The CAA applies primarily to large industrial sources (e.g., power plants, chemical manufacturers, refiners) and motor vehicles, although smaller pollution sources (e.g., gas stations, paint shops) are also regulated. No direct reference was found in the CAA regarding air pollution restrictions from the evaporation of GA fuel samples, although as noted earlier, gas stations and vehicle manufacturers are required to install vapor recovery units to capture gasoline vapors from these sources. It is unlikely that the quantity of GA fuel sample discards is a significant regulatory vapor source, given that this discard quantity (125,000 gallons) is only 0.00009% of the 133 billion gallons of gasoline dispensed and consumed in the United States in 2012 (*16*).

Regarding the CWA, the most significant regulation applicable to GA fuel sampling and disposal is likely the stormwater provisions established in the CWA's National Pollution Discharge Elimination System (NPDES). The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained, and the 1987 amendments to the CWA broadened the EPA's permit coverage to include stormwater discharges in addition to point sources. The NPDES program is administered through a series of discharge permits, monitoring requirements, and, in some cases, effluent limitations. Although ground discharge of sampled GA fuel could be construed as a violation of the CWA as defined above (i.e., ". . . discharge . . . into navigable waters . . ."), sampling of stormwater runoff from airports would be required to determine if the stormwater contained pollutants that would exceed certain CWA thresholds. It should be noted that NPDES permits are grouped by industry sector, and NPDES permits are only required for airports with de-icing operations.

Included in the federal regulations research was an inquiry to the local FAA flight standards district office (FSDO) in Philadelphia. The FSDO inspector indicated that there are no known FAA regulations or restrictions on the proper method for disposing of sampled GA fuel and recommended that the FAA Airplane Flying Handbook be consulted for additional clarity. The Handbook (FAA-H-8083-3A) was reviewed and no detail on how to dispose of fuel samples was included, although instruction on draining fuel during preflight and after refueling was covered.

State regulations. Other than the authority to implement the CAA and CWA as described above, states generally have their own set of environmental laws and regulations. State regulations regarding GA fuel sample disposal can be aviation-specific or could loosely fall under other regulated industry sectors such as aboveground storage tanks or general environmental protection. A state-by-state review of all applicable regulations is well beyond the scope of this research project; however, the following examples were identified during the research that indicate either a quantity-based direct ground discharge restriction or a general intolerance toward such practices:

- **Florida Department of Transportation (FDOT)—**"*Florida law prohibits dumping 'sumped' aviation fuel on the ground (soil, pavement, or waterway). Violators are subject to a fine of up to $50,000. See Section 403.727, Florida Statutes for details.*" (*17*).
- **New York State Department of Environmental Conservation (NYSDEC)—**"*Petroleum spills must be reported to DEC unless they meet all of the following criteria* (*18*)*:*
  - *The spill is known to be less than 5 gallons; and*
  - *The spill is contained and under the control of the spiller; and*
  - *The spill has not and will not reach the State's water or any land; and*
  - *The spill is cleaned up within 2 hours of discovery.*"
- **Maryland Department of the Environment (MDE)—**"*A person discharging or permitting the discharge of oil, or who either actively or passively participates in the discharge or spilling of oil, either from a land based installation, including vehicles in transit, or from any vessel,*

ship or boat of any kind, shall report the incident immediately to the administration." (Taylor GeoServices, Inc., unpublished work, October 2006). Note that no minimum quantity is specified, and this has been corroborated by communication with personnel familiar with gasoline station reporting requirements that MDE requires all releases, regardless of quantity, to be reported (J. Worth, email communication, November 7, 2013).

- **Other States.** Several states have an identified minimum reportable release quantity for petroleum hydrocarbons (e.g., gasoline, oil, etc.), below which reporting is not required, but under the assumption that the release does not impact navigable waters and does not cause a sheen or film on the water surface. Some examples include Delaware, Ohio, and Virginia, all of which have a minimum reportable quantity of 25 gallons (Taylor GeoServices, Inc., unpublished work, October 2006; J. Worth, email communication, November 7, 2013).

Local regulations. Local regulations can come in two forms: (1) municipal-specific ordinances and environmental regulations or (2) airport-specific environmental plans such as Stormwater Pollution Prevention Plans (SWPPP) or Spill Prevention, Control, and Countermeasures (SPCC) Plans.

Some airport-specific plans contain guidelines or recommendations for proper fuel sample management. For example, Seattle-Tacoma International Airport's SWPPP (*19*) provides fuel storage and delivery best management practices in Table 09 by stating "Use GATS jars to take fuel samples. Dispose of samples at designated collection sites. Use fire-rated containers for storage of fuel samples." This statement was contained near the end of the SWPPP, and it is unclear whether these types of documents have the force of law, and if so, who enforces them and how a GA pilot would know to review such a plan.

CURRENT STATE OF THE PRACTICE

The research conducted herein has shown that there is a wide range of fuel sampling and disposal practices currently being employed, and no clear industrywide consensus of how the sampling and disposal should be conducted. Although the ultimate goal of this research project is to develop fuel sampling best practices, it is important to first review the current state of the practice as a baseline to identify potential improvements. The current state of the practice was identified via the following four discrete research methods, all of which are described in more detail in the following subsections:

1. Literature and Internet research.
2. Inquiries to various aviation groups.
3. Field-based observations.
4. Pilot survey.

Literature research. Literature research included scouring and querying numerous scholarly databases (including the National Academies TRID Database), regulations, Internet sites, aviation manuals, pilot operating handbooks (POH) and videos. A majority of the information obtained from this research is incorporated into the text of this Digest as appropriate. However, as it applies specifically to the state of the practice, the following noteworthy items were identified:

- **Aircraft POHs—**Numerous POHs were reviewed, and although all made reference to pre-flight fuel sampling procedures, all were silent on how to manage the fuel samples once collected.
- **Aviation Manuals—**Pilot training and operating manuals were reviewed, and as with the POHs, reference was made to sampling but not to sample disposal.
- **Online Videos—**A cursory search of YouTube was conducted using the keyword "preflight." Of the first five videos where GA pre-flight fuel sampling was presented, three of the five videos (60%) showed the ground discarding of the fuel samples (*20*).
- **Previous Work—**The literature research revealed that the fuel sampling and disposal issue is not new and has been evaluated and debated for several years. For example, the quantity estimate of 3 million gallons previously mentioned was originally calculated in 1989. Additionally, aviation associations such as AOPA have published articles on the topic as far back as 2003. Furthermore, a proposal was prepared by the Aviators Model Code of Conduct in 2006, for consideration by FAA's Aeronautical Charting Office, to add "Collection Sites" to all airport diagrams such that pilots knew where to properly dispose of fuel samples, used oil, and other similar wastes

(*10*). Follow-up documentation from the FAA indicates that the issue was considered and declined and the issue closed (*21*).

Inquiries. Phone, email, personal, and/or website inquiries were made to several aviation associations, fixed-based operators (FBOs), flight schools, and airport managers to identify the fuel sampling and disposal procedures in practice at various facilities. Results of the inquiries are summarized on Table 1 and show a wide range of best practices and responsiveness, but a clear effort on the part of many organizations to properly manage fuel samples.

Field observations. Field-based research was conducted at three GA airports by positioning a field technician at a central location for 4-hour blocks of time (8 AM to Noon) on three consecutive Saturdays. The intent of the field research was to qualitatively ground-truth the sampling/disposal responses from the pilot survey (see below), and not necessarily to generate quantitative research data. As shown in Table 2, limited sampling/disposal operations were observed during the field research. However, for those operations observed, they confirmed a range of disposal habits, including return of fuel to the aircraft fuel tanks (37%) and ground discarding (63%). The

Table 1 Summary of inquiries.

Date	Method of Inquiry	Type	Response?	Response Notes/Findings
9/4/2013	Phone	Airport	YES	Five flight schools on the field. Airport has provided disposal containers about the field for pilots, but they never get used. Airport sells ~300,000 gallons of avgas per year.
9/9/2013	email	Aviation Association	Yes	Association-owned aircraft are equipped with GATS jars to return sumped/sampled fuel to the fuel tank. Each hangar is also equipped with a disposal can. This is a written policy to be included in the next revision of the policy manual. Association also publishes safety advisories for its constituents on how to best manage sumped/sampled fuel.
9/9/2013	Phone and site visit	FBO/Flight School/ Charter	YES	Facility provides 5-gallon buckets for fuel disposal. New pilots are taught to dispose in the bucket or return to the fuel tanks. Impetus for the disposal practice is to preserve the pavement, as advised by the pavement contractor. Fuel in the bucket always evaporates and doesn't accumulate.
10/2/2013	Phone	FBO	YES	FBO provides a fuel disposal container, but pilots don't use it and it is always dry. Container was placed at the request of the airport authority.
10/8/2013	Phone	Airport	YES	PI called based on a presentation found online by the airport environmental manager. One of the slides indicated a ranking of "[Airport's] Highest Ranked Impacts" and #3 was fuel sumping by GA (3 of 7). PI asked if this was supported by data, and manager indicated no, it was a gut feel. Airport has disposal containers about the airport but they are not used. An action item on manager's list is to remind the FBOs/flight schools of the containers. No metals, oil and grease (O&G), or VOCs are ever detected in their NPDES stormwater samples. The driver for the containers was good environmental stewardship.

observations also revealed that few pilots sump their tanks following refueling. No observations of fuel vent leakage or tank overfilling were witnessed.

Pilot survey. The electronic pilot survey provided data about overall pilot sampling/disposal behaviors (in addition to the discard quantification data). Specifically, question 7 (What do you do with the fuel sample(s) once they have been collected and inspected?) revealed that close to 40% of pilots discard the fuel samples to the ground regardless of the sample condition, whereas approximately 60% of pilots manage the fuel samples by either returning them to the aircraft fuel tanks or disposing of them in a ground-based container. The field-based observations corroborate the pilot survey data (i.e., pilots engage in a range of disposal behaviors); however, the percentages do not totally correlate. The field-based research showed approximately 63% of pilots discard the fuel samples to the surface, whereas the pilot survey data showed approximately 40% of pilots engage in this behavior. This data disparity is considered minor and is not unexpected, given the responses from the pilot survey and the inherent tendency of respondents to provide a positive response (e.g., I return my samples to the tank), despite the anonymity of the survey.

OBJECTIVE 2—BEST PRACTICES

Regardless of the estimated quantity of fuel discarded to the surface as determined in Objective 1, or the potential impact this practice may have on the environment or the airport infrastructure, this practice is economically wasteful, legally questionable, and easily avoidable with the implementation of any number of best practices.

The term best practices has many definitions, but can generally be defined as physical, structural, or managerial procedures that, when implemented, will achieve a common goal. Best practices are adaptive learning processes, as opposed to a fixed set of rules or guidelines that can be modified and improved with time and use. In the case of GA fuel sampling and disposal, the best practices can be separated into one of three categories: pilot-based, airport-based, and aviation community-based. The goals of these GA fuel sampling and disposal best practices are to mitigate environmental impacts, comply with applicable regulations and optimize fuel economics. The following sections present several aviation best practices that can be used, either singly, or in combination, to achieve these goals.

It should be noted that the recommendations for best practices provided in this Digest are in no way a confirmation that the current state of GA fuel disposal practices have, in fact, a documented impact on environmental media (e.g., surface water, groundwater, stormwater, soil, sediment, or air) or that implementation of these best practices will mitigate any presumed impacts. A rigorous sampling and monitoring program would be necessary to confirm any cause-and-effect relationship or to evaluate trends in stormwater quality improvement as a result of implementation of these best practices.

Pilot Best Practices

Pilot-based best practices are the most effective means of achieving the overall goals, given that the pilot is the source of the activity, and it is always most efficient to address issues at the source, as opposed to implementing subsequent measures downstream to counteract the initial behavior. Additionally, the regulations reviewed as part of this research generally place the responsibility for discharges, clean up, and reporting on ". . . the person in charge . . ." or ". . . the person responsible for the discharge . . ."

Pilot-based best practices include fuel sampling equipment that allows filtration and re-use of the fuel in the aircraft, and modifying pilot behavior to encourage the re-use, re-purposing, or proper disposal of fuel samples. These best practices are discussed in detail below.

Fuel sampling equipment. Field testing of three fuel sampling devices was conducted as part of the research project. A summary of the testing procedures and results is provided below.

All three samplers employ essentially the same technology: a fine mesh screen which, when pre-wetted with fuel, permits the passage of uncontaminated fuel while holding back water or particulate. Fuel (100LL) was pre-dosed with water and tested in triplicate in each of the three sampling devices. Based on the testing, all three products were able to remove water and particulate contamination from the fuel samples while allowing the uncontaminated fuel to be returned directly to the aircraft fuel tanks. Additionally, all three devices were able to capture essentially all of the pre-dose water. As such, it can be presumed that this water (if encountered), albeit

Table 2 Summary of field observations.

Date	Time	Annual Operations (airnav.com) and Tower/Non-Tower	OPERATION TYPE			AIRCRAFT TYPE		
			Refuel	Pre-flight	Other	High/ Low Wing	Single	Twin
8/31/2013	0840	24,820 - Non-towered		X		low	X	
8/31/2013	0900	24,820 - Non-towered		X		high	X	
8/31/2013	1030	24,820 - Non-towered	X			low	X	
8/31/2013	1120	24,820 - Non-towered	X			high	X	
9/7/2013	0845	90,155 - Towered		X		high	X	
9/7/2013	1130	90,155 - Towered		X		high	X	
9/14/2013	1015	27,010 - Non-towered	X			low	X	

likely containing some dissolved constituents of petroleum hydrocarbons, is mostly water and can therefore be discarded to the ground. Based on these results, these products are appropriate as a best practice for proper re-use of fuel. It should be noted that no regulations were encountered during this research project that indicate a restriction of fuel re-use in the aircraft.

Pilot practices. Pilot best practices include re-using or properly disposing of the fuel samples. More details on each of these best practices are provided below:

- **Re-use fuel samples—**The purpose of fuel sampling is to visually inspect the fuel for contamination. If visual contamination is not present, the samples can be returned to the aircraft tank with minimal risk of unforeseen micro-contamination. Note that over 92% of the pilot survey respondents indicated that they either *never* or *very infrequently* experienced contamination in their fuel samples. This practice is distinctly separate from the use of filtration sampling devices as described in Pilot Best Practices subsection.
- **Dispose of fuel samples—**If re-use is not an option, the fuel samples can be placed in an approved ground-based fuel container for future re-purposing or proper disposal. This best practice is discussed further in the Airport Best Practices section.
- **Re-purposing fuel samples—**A review of regulations and inquiries to the EPA regarding any restriction of re-use, considering that 100LL contains low levels of lead, was performed. The CAA regulates fuel usage and contains restrictive language and civil penalties for leaded fuel usage in motor vehicles labeled with "unleaded gasoline only" (CAA Section 211(g)(1) Misfueling). Although Section 216(2) of the CAA defines motor vehicles as ". . . any self-propelled vehicle designed for transporting persons or property on a street or highway," further review of background CAA documents and discussions with EPA personnel indicate that the topic of misfueling does apply to non-road vehicles as well.

FUEL SAMPLING/STRAINING OBSERVATIONS							
Sumping Occur? (Y/N)	Qty Sumps	Sampling device	Qty to Tank	Qty to Ground	Qty to Canister	Cockpit fuel drain	NOTES (include overflow and vent release observations)
Y	4	test tube	1	3	0	0	Personal (Archer/Dakota) parked outside on ramp
Y	3	unknown	0	2	0	0	Flight school
N	unknown	N/A	0	0	0	0	Personal (Dakota) refuel at pumps
N	unknown	N/A	0	0	0	0	Personal (Aeronca Champ) refuel at pumps
N	unknown	N/A	0	0	0	0	Flight school. Flaps down, so not sure if plane was already preflighted and we missed sumping observation. Not included in totals.
Y	2	test tube	2	0	0	0	Private overnight transient
N	unknown	N/A	0	0	0	0	Experimental refuel at pumps
TOTALS	**8**	**N/A**	**3/8 (37%)**	**5/8 (63%)**	**0**	**0**	

Specifically, the EPA provided proposed and final rule language (*22*, *23*) from a recently-promulgated misfueling regulation pertaining to ethanol-containing fuel (E15). The U.S. EPA opined that the use of lead in non-approved engines would be considered similar to the E15 scenario, including penalties for misfueling. Following these discussions with the EPA, it appears that re-purposing of leaded avgas in non-road, airport-based equipment could only occur under one of three conditions: (1) the equipment would have to be approved for leaded fuel use (i.e., an old engine manufactured prior to leaded fuel restrictions), (2) the user would have to demonstrate to the EPA, likely through rigorous testing, that the equipment could still meet applicable emission regulations while using the leaded fuel, or (3) the user would have to make a legal argument that the CAA regulations do not apply to this condition. Assuming that the misfueling of E15 is akin to re-purposing of leaded fuel as discussed herein, the E15 proposed and final rules confirm that misfueling violations can result in a civil penalty up to $37,500 for every day of each such violation.

Airport Best Practices

Various airport-based best practices can be implemented to achieve the quality goals. The practices are interrelated and interdependent but can generally be described as either physical, operational, or administrative. These are described below.

- **Physical**—Physical best practices can include placement and usage of containers to temporarily store fuel samples until the fuel can either be properly disposed of or re-purposed. Containers should be Type 1 metal safety cans with self-closing spring-loaded caps and anti-flashback devices approved by the Occupational Health and Safety Administration (OSHA) (1910.106(a)(29)). Individual can capacities cannot exceed 5 gallons, and no more than 25 gallons of gasoline can be stored collectively in safety cans outside of an approved storage cabinet, per OSHA. Other physical best practices may include stormwater management features constructed as part of an airport's stormwater management and control infrastructure. Table 3 provides a summary of example stormwater control measures (SCMs) that can be used to control, contain, and improve stormwater quality; however, it should be explicitly understood that the presentation of these SCMs in this Digest is in no way a suggestion that airports are required to or should install these features. Rather, if an airport is in the process of expansion or development, and SCMs are required as part of the development process, Table 3 provides examples of SCMs which are consistent with stormwater runoff containing petroleum hydrocarbons.

- **Operational**—Airport operational best practices include those standard operating procedures that are either voluntarily implemented or required by regulation or permit to control or monitor environmental conditions. One such operational procedure is to advise airport refueling personnel that topping off or overfilling of aircraft tanks is discouraged. Topping off or overfilling of tanks can cause an immediate release of fuel to the ground. Additionally, filling tanks to the very top, followed by an increase in ambient temperature, can cause the fuel to expand and release through the overfill vents. Avgas expands approximately 1% per 10 degrees Celsius (°C) of temperature increase (*24*). Therefore, if a GA aircraft fuel tank containing 25 gallons is topped off at 10°C (50° Fahrenheit [°F]) and the temperature increases to 30°C (86°F), one-half gallon of fuel can be released through the overflow system. This is not an insignificant quantity of fuel, but it is also a fairly extreme increase in ambient temperature (36°F) that is not experienced frequently. Regardless, this overflow quantity underscores the need for refueling personnel and pilots to be aware of the environmental, regulatory, and economic consequences of filling aircraft tanks to the very top.
- **Administrative**—Administrative best practices involve the implementation of airport-based policies which are driven by the airport's permits or other regulatory obligations. These policies are documented in manuals such as an SPCC plan or an SWPPP. Generally speaking, these types of administrative best practices are only as strong as the system of procedures and personnel charged with overseeing and enforcing them. This was evident during the research inquiries (see Table 1), whereby several facilities (airports) made attempts to encourage best practices (e.g., providing disposal cans) but there was a general acknowledgment that, in reality, the cans go unused. Other administrative best practices can include airport signage or postings to describe the appropriate method of fuel sampling and disposal and the negative impacts (or regulatory infractions) of ground discarding.

Aviation Community Best Practices

In the context of fuel sampling and disposal best practices, the aviation community is a broadly defined term that includes various stakeholders with a potential interest in this issue, including flight schools, flight training organizations, aviation associations, and aircraft manufacturers. The best practices for this segment of the aviation community are generally more onerous and far-reaching and may not be easily implementable without significant effort, corporate will, or external motivation. Regardless, this Digest would not be complete without a review of *all* potential best practices that can achieve the intended goals. Examples of aviation community best practices include the following:

- **Flight Training Organizations**—Primary flight training is the first opportunity to instill certain behaviors in student pilots. Through standardized fuel sampling best practices, the flight instructors can make a significant impact on future pilots. Therefore, flight instructors, flight schools, and especially the organizations that prepare the primary flight training manuals should modify their procedures to incorporate the fuel sampling best practices contained in this Digest. It should be noted that a trend in more appropriate fuel sample disposal practices (e.g., re-use or disposal as opposed to ground discard) was discernable in the pilot survey data when comparing the disposal behavior results (question 7) to the pilot's primary training era (question 10). This is an indication that appropriate best practices are beginning to be

Table 3 Summary of example stormwater control measures.

Stormwater Control Measures (SCMs)	Description	Treatment Effectiveness	Capital Cost	O&M Requirements
Detention Basin	Dry basin with outlet structure to control stormwater peak flow. No mechanism for water quality treatment.	LOW	LOW	LOW
Infiltration Basins, Beds, and Trenches	Primarily for stormwater volume reduction via infiltration. Water quality treatment only occurs as an unintended consequence of infiltrating through underlying soil. Can result in groundwater contamination if sufficient treatment doesn't occur.	LOW	HIGH	LOW
Wet Pond/Retention Basin	Basin with permanent pool of water to support vegetation and promote treatment through sediment settling, evaporation, and transpiration.	MODERATE	LOW	MODERATE
Rain Garden/ Bioretention	Engineered "depression" or basin with a subsurface layer of organics to support vegetation and promote filtration and biodegradation.	HIGH	MODERATE	MODERATE
Constructed Wetland	Large treatment basin with permanent pool, vegetation, and varying "engineered" zones to provide treatment via physical and biological mechanisms. Generally requires large land area to construct.	HIGH	MODERATE	MODERATE
Engineered Filters and Structures	Filters and/or hydrodynamic units in engineered basins or structures. Generally small units designed for small drainage areas. Includes proprietary pre-packaged treatment units.	HIGH	HIGH	HIGH
Oil-Water Separator	Treatment unit with multiple chambers and weirs to separate and capture oil (free-phase, non-dissolved) in stormwater runoff.	HIGH	HIGH	HIGH

NOTE: all ratings (low/moderate/high) are for relative comparison purposes only regarding treatment of stormwater containing petroleum hydrocarbons.
O&M: Operations and Maintenance.

implemented as part of primary flight training and this movement should be capitalized on and re-enforced moving forward.

- **Aviation Associations**—Associations such as AOPA, Civil Air Patrol, and numerous others should disseminate (or continue to disseminate) this type of information to educate the aviation community and their individual constituents on the appropriate best practices. This can be accomplished via newsletters, email blasts, and/or webinars, to name a few.
- **Aircraft Manufacturers**—These are undoubtedly the most onerous of the fuel sampling best practices contained in this Digest, but as stakeholders, the aircraft manufacturers have a vested interest in appropriate fuel sampling and disposal practices. Best practices to be considered by aircraft manufacturers include the following:
  - Modify future POHs to address the appropriate methods of managing pre-flight fuel samples.
  - Modify future aircraft designs to do away with remote or cowl-based fuel strainers that make fuel sample collection difficult.
  - Ensure that all future high wing aircraft have an easy means of accessing the fuel tank filler area to return fuel samples to the tank.
  - Modify future aircraft to have an integral fuel screen mechanism or provide an appropriate filtering fuel sampler with each new aircraft.
  - Modify future aircraft to have fewer fuel tank sumps so there are fewer fuel samples generated. Data from the pilot survey (question 2) indicate that some single-engine aircraft have up to 13 sump locations.

OBJECTIVE 2—SYNOPSIS
Best Practice Suggestions

Pilot Best Practices (implement at least one)

- Use filtering fuel samplers to return samples to the fuel tank
- Re-use fuel samples in the aircraft if not contaminated
- Properly dispose of fuel samples

Airport Best Practices (implement any that are applicable and practical)

- Provide fuel disposal containers
- Avoid overfilling and topping off of aircraft tanks
- Implement, encourage, and enforce proper disposal practices

Aviation Community Best Practices (consider implementing)

- Teach proper disposal practices at the primary flight training level
- Disseminate proper disposal practices via aviation associations
- Consider airframe, engine, and pilot operating handbook (POH) modifications in future aircraft designs to encourage proper fuel disposal

CONCLUSIONS AND SUGGESTIONS

Conclusions that can be drawn from this research project include the following:

1. An estimated range of between 75,000 gallons and 175,000 gallons of avgas is discarded to the ground surface each year by GA pilots.
2. Environmental impacts to air, surface water, groundwater, and soil occur from the release of petroleum hydrocarbons to the environment. Environmental impacts from GA fuel discarding cannot be confirmed, quantified, or evaluated without further research.
3. Numerous local, state, and federal environmental regulations potentially apply to GA fuel sampling and disposal activities. A review of these regulations indicates that ground discarding of avgas may be in violation of certain regulations.
4. The current state of the practice for GA fuel sampling and disposal varies and includes a segment of the pilot community that discards samples to the ground surface (40% to 63%) while others re-use or properly dispose of the fuel samples. Trends in the survey data indicate a marginal temporal movement away from ground discarding for more recently trained pilots.
5. The value of the discarded avgas is between \$450,000 and \$1,050,000 annually (at \$6.00/gallon).

6. The localized degradation of airport infrastructure, namely asphaltic pavement, occurs as a result of the discard activity.

Suggestions developed as part of this research include implementation of various best practices and potential future research on the topic as follows:

1. Pilots should implement at least one of the following best practices:
   a. Use filtering fuel samplers to return filtered fuel samples to the aircraft.
   b. Re-use fuel samples in the aircraft if not visually contaminated.
   c. Properly dispose of fuel samples that are either contaminated or are otherwise not amenable to re-use or re-purposing.
2. Airports should consider implementing any of the following best practices which may be applicable to the facility and practical to implement:
   a. Place fuel disposal cans at locations about the airport that are convenient for and will be used by pilots for fuel sample disposal.
   b. Instruct aircraft re-fueling personnel not to top off or overfill aircraft fuel tanks.
   c. Implement and enforce best management practices or other procedures that are included in the airport's SWPPP and/or SPCC plan.
   d. Prepare and post signage or other educational materials at key airport locations informing the aviation community about fuel sampling and disposal best practices and the potential implications of ground discarding.
3. Aviation community stakeholders should consider implementing some of the best practices presented in this Digest for the stability and betterment of the GA sector.
4. Suggestions for future research or best practices support include the following:
   a. Fund additional research, specifically airport stormwater sampling and monitoring, to identify if the current fuel sample discard practice is, in fact, having an appreciable impact on the environment.
   b. Fund the preparation of generic, informative signage and educational materials on the topic of fuel sampling best practices that can be distributed to and used by GA airports.
   c. Disseminate the information in this Digest to the aviation community.

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500 Fifth Street, NW
Washington, DC 20001

ISBN 978-0-309-28413-4
90000
9 780309 284134

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