

8 The logistics of bread production in Old Kingdom Egypt

A nutritional perspective

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Introduction

Human survival is, in every way possible, determined by the logistics of food provisioning. The global food chain comprises one of the largest industries of the modern world, shaping – and being shaped by – economics, politics, and environments. For this reason, understanding the food supply chain of any ancient society reveals insights not only into ancient diet and agriculture, but also into economics and daily activities, social organization and ethics. Prior to the development of the modern industrialized food chain, food production was naturally a matter that consumed a great deal of energy and planning in society in general, and in the daily lives of individuals. Maximizing output and minimizing labour within the food chain would undoubtedly have been a matter of great concern. To understand the ways in which food supply chain logistics worked and how food production affected ancient lives, or how it shaped economics and politics, we have to first answer some basic questions: what types of food were available? Where were crops grown or animals reared? How and where were foods processed? Was food transported and/or distributed and if so, how? How much did people eat, and who ate what? Some of these questions are easier to answer than others, but the relationship between potential demand and the logistics of the supply chain to meet that demand is key to them all.

Addressing these issues in archaeology is naturally complex. The sources of evidence (written, artistic and archaeological from both domestic and funerary contexts) can be ambiguous and are inherently open to varying interpretations. Equally, the archaeological remains in settlements are affected by such factors as site preservation (or lack thereof), site formation processes, taphonomy, and varied archaeological techniques. Most critically, the food was, of course, consumed – leaving only traces of production waste and tools. However, by taking a nutritional approach using human physiological hunger and need as starting points, it is possible to create an outline or ‘model’ of the potential logistics of provisioning a known population. As Redding (2013) has shown, it is possible from this foundation to utilize the archaeological record to reconstruct aspects of the food supply chain and start to address more complex questions. Indeed, this paper was developed as a complementary study to Redding’s work on meat provisioning¹. Whilst

Redding developed a model for the supply of meat to the Old Kingdom Heit el-Ghurab ‘workers’ settlement on the Giza plateau looking at the quantity of protein required by a healthy adult male, I developed this parallel study of bread provisioning which focussed on the carbohydrate requirements of the inhabitants of the same settlement.

Existing studies

The focus of this chapter is not to critique past work, but to present this new approach to the issue of the logistics of the food supply chain in ancient Egypt; however, it is important to note that the issue of bread provisioning in ancient Egypt has only been touched upon by a few scholars in the past. Baer (1962), Simpson (1973), Mueller (1975), Saffirio (1975; 1977), Kemp (1986; 2006, 171–9), Miller (1991), Allen (2002) and Gal (2013) have each made useful contributions to the issue. In general, these studies examine the textual evidence for bread rations/wages and discuss the caloric content of those rations, sometimes looking at the issue of land yield/requirements. Each author took a different approach to the issue and used different data and, to avoid inappropriately lengthy discussion, it is sufficient to say that the publications vary in their reliability. For example, Baer ran a series of calculations aiming to ascertain the portion of a crop retained by (and the calories available to) a tenant farmer in a study of land value, but made an error in his calculations of seed grain listed in P. Louvre 3171 which meant that all his subsequent results were flawed². The most critical error perhaps was made by Simpson (1973), as his mis-translations of bread ‘dockets’ from Uronarti have been relied upon by several other scholars (e.g. Kemp 1986). These inscribed wooden items were discovered during excavations at the Middle Kingdom fortress of Uronarti in (what is now) the Sudan, and appear to be ration ‘tokens’ or ‘dockets’ of bread deliveries. Two bear inscriptions listing how many units of bread were baked using specified quantities of different grains. Naturally, these small texts are vital pieces of evidence for this discussion, but unfortunately Simpson made an error in his transcription of the dockets³. This publication has been relied upon without question by several scholars since then, meaning that all the calculations run based on his translation are incorrect; only Allen noticed Simpson’s mistake (Allen 2002, 148 n.44).

To date, a lack of attention to the importance of a proper understanding of human nutrition has led to sweeping generalizations which overlook many important issues. For example the topic has never really been approached in ways that reflect the complexity of the supply chain; the numerous variables that would have affected food provisioning, and the number of different stages involved in the production, procurement, processing, and delivery of the basic staple foods have barely been mentioned, although Warden (2014) does address some parts of this. One especially pertinent issue which affects the analyses of ancient Egyptian texts is the fact that we can never be 100

per cent certain of the correct modern equivalent for the ancient measurements listed in texts – and indeed, the likelihood that their measurements were consistent is very slender (Allen 2002, 143–59).

One useful comparative study in which the logistics of a food supply chain was studied in detail is an extensive study of bakeries and bread production by Benton (2014). The situation of the study of food supplies in the Roman world is similar to that of ancient Egypt – dominated by texts and artistic representation, with occasional studies of individual aspects of the production process (Benton 2014, 1–4; for everyday foodstuffs and their preparation in Pompeian houses, see also Allison, this volume). Of major advantage in Roman archaeology are the results of the AD 79 Vesuvius eruption, which left the cities of Pompeii and Herculaneum almost ‘perfectly preserved’ – frozen in a moment in time – including (in Pompeii) bread preserved in the oven. The *in-situ* preservation of all the ‘tools’ of bread production in Pompeii and Herculaneum are invaluable because they show what is usually missing from the archaeological record elsewhere (Benton 2014, 80). As a result, Benton was able to reconstruct many aspects of bread production/provisioning in Pompeii.

A new approach

The methodology Redding and I have developed introduces a new approach, taking human physiological needs as a starting point from which to build a food supply chain ‘model’. Here I focus on the supply and demand of bread – one of the basic staple foods of ancient Egypt. The so-called ‘pyramid workers town’ of the Old Kingdom on the Giza plateau (Fig. 8.1) is known by the modern Arabic name of Heit el-Ghurab and has been excavated since 1988 under the direction of Mark Lehner by Ancient Egypt Research Associates (AERA) (Lehner 2015; see also www.aeraweb.org for all publications). This site is an ideal candidate on which to develop this case study; it has been extensively excavated using detailed archaeological methods, the town contains ‘barracks’ type dormitory accommodation blocks for which the population can be readily estimated, there are food production and storage facilities preserved within the town, there are ample faunal remains and some useful botanical remains, and there is relevant human osteological data for reconstructing details of the inhabitants’ physiology⁴.

It should be noted that this town was not the home to the primary workforce of the pyramid construction projects. The settlement has a number of different areas of housing, including large dwellings for scribes and officials who were most likely involved in the administration of pyramid construction (Fig. 8.2). Significantly, the ‘barracks’ or ‘galleries’ area is thought to have been used by either the higher level workers (skilled masons, etc.) and/or expeditionary troops passing through the area on their way to quarries or on trading missions (Lehner 2013), and therefore the assumption is that the inhabitants of the ‘galleries’ were likely to be predominantly active healthy adult males.

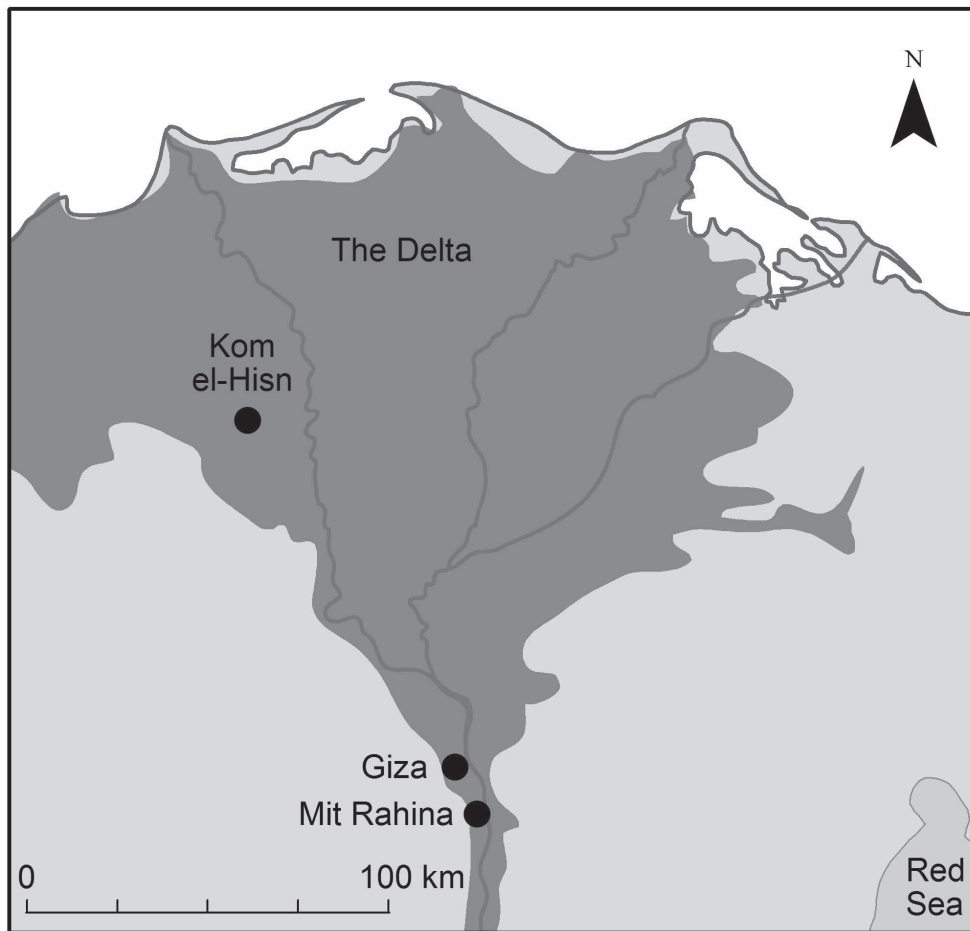


Figure 8.1 Map showing location of HeG site (Copyright 2016 by Ancient Egypt Research Associates [AERA])

It should be stressed, however, that this is a work-in-progress and that there are limitations to the results. Only the stages of production that relate to the quantity of bread, grain and land required, and the number of people involved in producing the bread and grain are presented here. As was the case with Redding's study, I make a number of assumptions and educated estimations throughout in order to simplify the process.

The data and sources used in this study are: human osteoarchaeological remains from Old Kingdom cemeteries (Raxter et al. 2008); nutritional information of African-grown emmer wheat (Wu Leung 1968); experimental work on emmer wheat grinding (Samuel 2010); modern data on emmer wheat volume/weight (Konvalina et al. 2008); historic crop yields (presented in Miller 1991); historic labour records (presented in Baer 1962); archaeobotanical data from Heit el-Ghurab (Malleson forthcoming; Malleson and Murray 2015; unpublished AERA data); ethnoarchaeological data on emmer processing (Kooistra 1996); archaeological evidence for living quarters, baking and storage facilities at Heit el-Ghurab (Lehner 1992; 2015; Murray 2011; Sadaranghani, unpublished AERA internal report);

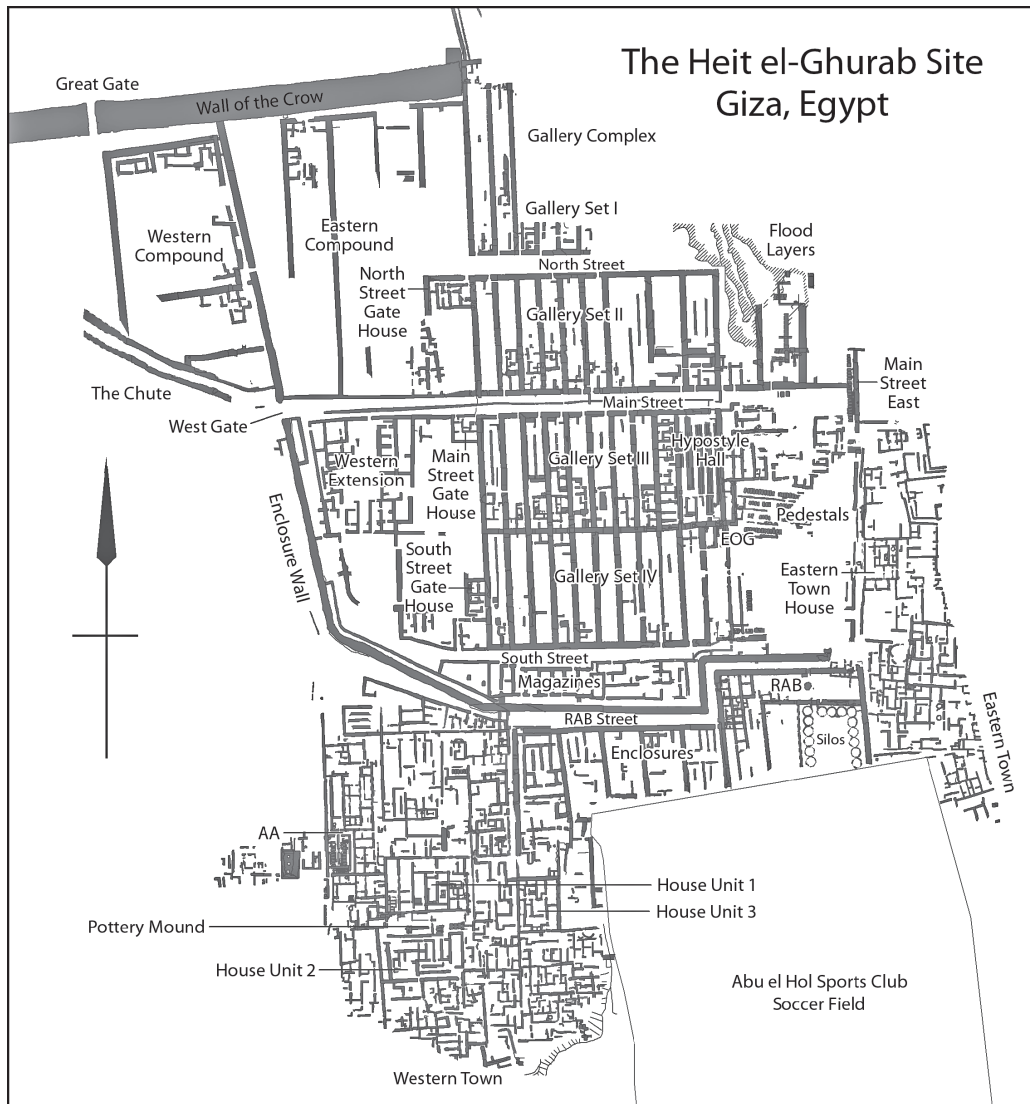


Figure 8.2 Plan of HeG (Copyright 2016 by Ancient Egypt Research Associates [AERA]).

and ceramics from Heit el-Ghurab (Warden 2014; Wodzinska 2013). Texts used are: Uronarti Middle Kingdom bread ‘dockets’ (Allen 2002; Simpson 1973); the Hekanakhte letters (Allen 2002; James 1962); P. Valençay I (Gardiner 1951); P. Bologna 1086 (Wolf 1930), P. BN 204, 205, 206, 207, 209 (Spalinger 1986); and ‘Griffith’ fragments (Gardiner 1941).

The logistics of provisioning bread to Heit el-Ghurab

Caloric requirements

The first, necessary step was to ascertain the basic caloric requirements of the individuals living in the town. This was done this using the most widely accepted method of calculating the basal metabolic rate (BMR) of

healthy people. Basal metabolic rate determines the daily calorie requirements needed to maintain adequate health, free from nutritional related disease and illness. The most common way of doing this is to use the internationally recognized Harris-Benedict formula. This takes into consideration the weight, height, age and gender of an individual (Frankenfield et al. 1998). As noted above, all calculations were run on the assumption that the population of the galleries was 100 per cent healthy adult males⁵, and although these men were not the labourers, high activity levels are assumed. The formula was revised in 1984 (Roza and Shizgal 1984) but the original formula is in more widespread use, so this was chosen to run the calculations.

- The Harris-Benedict formula for a male engaging in exceptionally high activity levels = $(66 + (5 \times \text{height}) + (13.7 \times \text{weight}) - (6.8 \times \text{age})) \times 1.9$.

The most recent and reliable study of the physiology of ancient Egyptians was published by Raxter et al. (2008). The study was based on analyses of ancient Egyptian skeletal remains, the majority of which derived from the Old Kingdom cemeteries at Giza (the Fifth dynasty tombs above Heit el-Ghurab and Fourth-Sixth dynasty mastabas in the Western Cemetery), of both 'workers' and 'officials'. Their results show that the height range for Old Kingdom (Giza) male was 145 to 175 cm, the average therefore being 160 cm. Based on an educated estimation of likely range of age and weight, BMR calculations for males aged 16–20, weighing 60–65 kg and 160 cm tall were run.

- BMR Range 2949–3131. Average requirement = 3,040 kcal/day.

Carbohydrate requirements

It is not sufficient simply to look at the basic caloric requirement of the individuals. To maintain good health (free from nutritional related disease triggered by deficiencies) it is important to consume adequate quantities of macro and micro-nutrients (proteins, fat and carbohydrate, vitamins and minerals). For the model of meat-protein provisioning at the settlement, see Redding (2013).

The two primary sources of carbohydrate in the ancient Egyptian diet would have been bread and beer, made from hulled barley (*Hordeum vulgare* L.) and emmer wheat (*Triticum turgidum* (L.) subsp. *dicoccum* (Schrunk) Thell). It is generally thought that bread was made from emmer wheat, whilst barley was used in beer production (Murray 2000, 512). For the sake of simplicity at this stage, the assumption is that bread was made using 100 per cent emmer wheat flour, and that 100 per cent of the men's carbohydrate requirement was fulfilled by eating bread. This is clearly not realistic; however, for the purposes of creating a baseline from which to develop additional variables, and at this early stage in the development of

the methodology, it is necessary to begin with just one variable for carbohydrate provisioning.

Calculations of carbohydrate requirements were based on guidelines provided by government bodies. At present, government guidelines for optimal health vary from country to country⁶. Based on the fact that sports nutrition is considerably more advanced and specific than generic population guidelines, and the fact that the men living in the 'barracks' are likely to have been active individuals, the American College of Sports Medicine guidelines were used (carbohydrate 50–60 per cent of total calories consumed, maximum 30 per cent fat, protein 15–20 per cent – ACSM [2009]).

- 3.040 kcal requirement
- 55 per cent carbohydrate
- 1 g carbohydrate = four calories

Thus the requirement is **1,672 kcal, 418 g of carbohydrate / day**.

It should be noted that most of the earlier studies of ancient Egyptian food provisioning (see above) considered bread rations as the only source of food, and their calculations were run for a higher number of calories from bread per day. This figure of 1,672 calories per day from bread (carbohydrate) is more realistic given the fact that we know from the rich faunal record that meat and fish was readily available at the settlement.

Quantity of emmer wheat needed to fulfil this requirement

Different species of wheat have different nutritional values, and to some extent those values will be dependent on the soil and growing conditions of the crop. Calculations were based on the closest possible match, namely emmer wheat grown in Africa (Wu Leung 1968). The values for split grains were chosen based on the fact the emmer had to be ground to make flour, but emmer *flour* may well have had higher values due to the fact that the grinding to flour would increase the digestibility and, therefore, the availability of the nutrients during digestion.

- 334 kcal (per 100 g)
- 2.2 g fat
- 16.9 g protein
- 67.5 g carbohydrate
 - $418 \text{ g carb required} \div 0.675 = 619.26 \text{ g emmer}$

Incidentally 619.26 g emmer provides 13.62 g fat and 104.65 g protein. This represents 14.66 per cent of the daily fat requirement, and 78.68 per cent of the daily protein requirement (although this is not complete proteins; the diet would need to combine bread with beans or be supplemented with animal products to truly fulfil protein requirements).⁷

How many loaves of bread needed to be baked?

Textual evidence shows us that the number of loaves in a standard ration given to workers/expedition troops in ancient Egypt depended largely on the status of the worker, but that the average basic ration was ten loaves (Muel-ler 1975).⁸ There is just one small group of texts which gives the quantity of grain required for a specific type of loaf. Inscribed wooden items from the Middle Kingdom fortress of Uronarti in (what is now) the Sudan, appear to be ration ‘tokens’ or ‘dockets’ of bread deliveries. The dockets record that 90 units of *trsst* bread are made from one *hekat*⁹ of wheat¹⁰. A complicat- ing factor is the use of *pesu* values to denote the ‘strength’ of the loaf in other texts (Kemp 2006). The *pesu* was not a fixed size, it was a variable translated as ‘baking value’; a high *pesu* meant many loaves / jars from one *hekat*, and a lower *pesu* meant fewer loaves / jars from the *hekat* – making a ‘stronger’ or richer product (Kemp 2006, 174–5). The problem here is that the ration lists do not give the *pesu* value so we have no idea what type of/ size of loaf (how much grain) was standard, so the question of ‘how many loaves?’ needs looking at from a different angle. The solution I suggest here is to calculate the number of loaves made by the known quantity of grain (619.26 g emmer per man per day), which is made easy by the fact that in ancient Egypt bread was frequently produced in standardized ceramic bread moulds.

The initial step in this process is to ascertain the volume of bread pro- duced by a known weight/volume of emmer flour. Calculations were based on experimental work conducted at the New Kingdom settlement of Ama- rna in Egypt by Delwen Samuel in the 1980s (Samuel 1989). She used exper- imentally made New Kingdom type moulds which had a volume of 130 ml each¹¹ and baked seven loaves¹² using 500 g flour with no added yeast (the issue of yeast in ancient Egyptian bread is discussed in Samuel 1996a):

- 910 ml bread per 500 g flour = **1.82 ml bread made per 1 g flour**

This ratio of bread/flour weight does fit within the rough gauge in which the weight of flour accounts for around 50–75 per cent of the quantity of bread produced (based upon various internet bread baking forums searched in May 2015).

Bread moulds are one of the most ubiquitous ceramic types found at any settlement site in Egypt, and during the Old Kingdom the standard bread mould was the conical *bedja* mould. The corpus of *bedja* moulds from Heit el-Ghurab has been studied in great detail by Wodzinska (see Wodzinska 2013 for an overview of the Giza ceramics corpus), who determined three distinct size categories for the bread mould assemblage. The average volumes of these bread moulds as calculated by Warden (2014, Table 5.5) were used:

- F2b (medium mould) average volume = 1,591.76 ml
- F2c (large mould) average volume = 7,687.5 ml

The third type of mould was discounted by Warden who considered the small F2a moulds to be miniature models (Warden 2014:159). My own calculations using rim diameter and pot height gave a volume of 239 ml capacity for this size of mould.

From this the quantity of emmer wheat needed to make each loaf size can be calculated.

- F2a mould = 239 ml ÷ 1.82 ml bread per 1 g flour = **131.32 g required**
- F2b mould = 11,592 ml = **874.73 g required**
- F2c mould = 7,687 ml = **4,223.63 g required**

The nutritional values of an F2a loaf made with 131.32 g emmer are therefore:

- 438.61 kcal
- 2.89 g fat
- 22.19 g protein
- **88.64 g carbohydrate**

Thus, each man needs **4.72 F2a loaves**

The nutritional values of an F2b loaf made with 874.73 g emmer:

- 2,921.6 kcal
- 19.24 g fat
- 147.83 g protein
- **590.44 g carbohydrate**

Thus, each **F2b loaf feeds 1.41 men**

The nutritional values of an F2c loaf made with 4,224.63 g emmer:

- 14,110.26 kcal
- 92.94 g fat
- 713.96 g protein
- **2,851.63 g carbohydrate**

Thus, each **F2c loaf feeds 6.82 men**

One of the major advantages of using the Heit el-Ghurab site as a basis for this model of provisioning is the fact that it is relatively easy to arrive at a population estimate, making it easy to then calculate the amount of bread required in the town on a daily basis, assuming the galleries were occupied to maximum capacity. The most recent population and requirement estimates for the Heit el-Ghurab accommodation gallery complex is 1,440 men (Lehner 2015, 436).

- 4.72 F2a loaves per man = **6,796.8 loaves per day**
- F2b loaf feeds 1.41 men = **1,021.28 loaves a day**
- F2c loaf feeds 6.82 men = **211.14 loaves per day**

Thinking a little more realistically, attempting to divide loaves up to feed 1.41 or 6.82 men is obviously impractical, as is providing exactly 4.72 loaves to each man; however, the actual (rounded) requirement of **211 F2c loaves, 1021 F2b or 6,797 F2a loaves** were used for the following calculations.

The overall quantity of grain required to bake these loaves is easily calculated. Working with the population estimate of 1,440 men each with a daily requirement of 619.26 g of emmer, a total of **891.73 kg emmer** is required per day. However, there is textual evidence from the New Kingdom (records from the bakeries supplying the temples of Seti I) showing that they calculated a loss of 10 per cent in the weight of flour/grain delivered to the quantity of bread produced (Spalinger 1986).¹³ This is easily understood since under no circumstances would any baker manage to use every single gram of flour in the baking process. Therefore, the overall quantity of emmer (flour) required on a daily basis has to be adjusted to **980.9 kg**.

The bakeries

The other major advantage of building this model around the Heit el-Ghurab site is the existence of the bakeries within the main gallery complex. Discovered in 1991, during the very early years of excavation at the site, two bakeries were excavated in the eastern end of the southern gallery set (Lehner 1992). Based on a combination of the excavation results and evidence from Old Kingdom funerary art (scenes depicting baking) it was possible to reconstruct the way in which these bakeries functioned. In 1995 a National Geographic project built a reconstruction of one bakery and ran experiments (Lost City Project 2015). Each bakery was an open building with low stone walls. At the back of the building were large deep ceramic vats for mixing dough, in one corner a hearth for heating the ceramic mould lids, and along one wall was a thick dense layer of black ash with small conical depressions. These conical depressions would have each contained a single bread mould – the hot ash and heated lid forming a mini one-loaf oven (a good illustration of the way these bakeries functioned can be found in Kemp 2006, Fig. 63).

Based on the fact that there were 24 bread mould depressions in the bakery it is assumed that each bakery unit could produce 24 loaves in one batch, although it would be equally valid to calculate how many of each size mould might fit within the ash-area of the bakeries – meaning that greater numbers of the medium F2b or small F2a *bedja* loafs could be baked in a single batch. It is probably safe to assume that each bakery produced several batches per day. During the National Geographic experiments it took around 1 hour 40 minutes to produce one batch of 24 loaves (AERA, unpublished site notebook). Allowing 2 hours 30 minutes per batch to mix, prepare and bake the loaves, and allowing ten working hours per day it might have been possible to produce up to four batches of loaves per day in a bakery.

- 6,797 small F2a loaves = **71 bakeries**
- 1,021 medium F2b loaves = **10 bakeries**
- 211 large F2c loaves = **2 bakeries** (numbers rounded)

Based on the fact that the large F2c *bedja* bread moulds are clearly the most economical option, it seems very plausible to suggest that the two bakeries within the gallery set buildings were responsible for providing for the entire accommodation complex.

Moving on to look at the labour involved in the bread production, based very simply on the practicality of how many people could have fitted into a bakery working at once, and the fact that the bread experiments were run successfully using just two people, up to a maximum of five people may have worked in each bakery, therefore requiring 355 workers to produce F2a loaves or, alternatively 50 workers (if F2b loaves are produced) or ten workers (if F2c loaves are produced).

Grinding the flour

The preparation of flour for baking would have involved a considerable amount of labour. Experimental work undertaken by Delwen Samuel at Amarna provides a good guide for the amount of time this process might have taken (Samuel 2010). Due to the structure of emmer wheat, the grains require pounding to remove the tough outer casing of chaff, prior to grinding. Samuel did not conduct detailed experiments for pounding as she did for grinding (milling) of emmer, so it is harder to calculate the time and labour required for the pounding stage of processing. Archaeobotanical data from the site suggest that it is possible that the pounding actually took place off-site, away from the main Heit el-Ghurab settlement. At most ancient Egyptian settlements one of the primary fuel materials was the by-products of cereal processing, used as a supplement to wood and dung (Malleon forthcoming; Murray 2009). The carbonization of the plant materials ensures their preservation, and the plant items can be identified by archaeobotanists. At the Heit el-Ghurab settlement there is a remarkable lack of cereal chaff in the ashes (unpublished AERA data. For a brief overview of the Giza archaeobotany, see Malleon and Murray 2015). This may in part be a result of the detrimental soil conditions at the site, but may also be due to a lack of these materials at the site in general; indicating that the cereals stored in the granaries at the settlement were in fact already cleaned and free from chaff. This obviously means that the pounding took place elsewhere. The job still had to be done, but it does mean that it may well not have taken place within the town.

Based upon Samuels' milling experiments, the number of time/people needed to produce the required amounts of flour was calculated. In her experiments, Samuel used emmer wheat and replica tools, concluding that 2 kg took three hours to grind (Samuel 2010:464; see also Hayden, this volume).

- Time required to grind 981 kg is **1,471.5 working hours**
- Assume each grinder works five to ten hours in a day
- Need **295–148 people** to grind the grain on a daily basis
- N.B. Would need the same number of querns

Grain supplies – land requirements

The grain requirement (including the 10 per cent losses) is 981 kg daily, therefore **358,065 kg annually**. The problem arises here of the weight–volume ratios of the grain. Most ancient accounts record the grain by volume, but the weight of grain per litre varies enormously dependant on the type of grain and the moisture content. Kemp (1986) based his calculations on data provided by Gentry in 1976 who looked at British Roman military establishments where the measure was given as wheat = 785 g per litre. More specific results are now available. A study of six different varieties of emmer showed a range of 727–743 g/litre (Konvalina et al. 2008, 542), the average therefore being **735 g per litre (1.36 ml per gram)**. Whilst this data derives from analysis of modern grains, it relates to emmer as opposed to the more generic data from Gentry, and is therefore far more appropriate for this study.

- $981 \text{ kg} \times 1.36 = 1,334.16 \text{ litres per day}$
- $358,065 \text{ kg} \times 1.36 = 486,968.4 \text{ litres annually}$

In order to ascertain the amount of land required, crop yield statistics are critical. Yield is dependent on many factors; soil type, soil quality, irrigation, grain species and crop husbandry. The many major transformations in Egyptian agriculture mean that modern crop yields cannot be used; in the past the ancient texts have been relied upon. Before looking at those texts, it is important to outline the ancient measurements. It is accepted that one *hekat* (wooden scoop used to measure grain) is equal to 4.78 litres, and the difference between the Middle and New Kingdom *khar* (sack) sizes is also widely accepted.

- One *hekat* = 4.78 litres
- One *khar* – Middle Kingdom = 10 *hekat* = 47.8 litres
- One *khar* – New Kingdom = 16 *hekat* = 76.48 litres
- One *aurora* (measurement of land) = 2,735 m²

The figures for the quantity of grain required reflect the quantity of clean, useable grain required to produce the bread. Emmer wheat requires a great deal of processing in order to obtain the clean grain – as noted above. Emmer wheat is believed to have been stored only partially threshed in ancient Egypt (Cappers, *pers. comm.* 2013; Kooistra 1996, 98). This method of storing ‘in the chaff’ is considered to have possibly been a measure taken to help prevent excessive pest damage to the grains since the chaff provides a physical barrier to pests such as grain weevils. What this means is that the measurements of the crop yields in ancient Egypt must have included this chaff – the sacks taken from the threshing yards contained both the grain **and** the chaff. In experimental work it has been shown that within a granary containing partially threshed emmer, spelt or hulled barley, around 25 per

cent of the of the granary contents consisted of chaff (Kooistra 1996, 98). Therefore, the emmer yield statistics available from ancient Egyptian texts reflect the yield of grain **and** chaff, and so the quantities should be adjusted accordingly to reflect the actual grain yield.

Only one ancient text actually provides explicit emmer yield data. In fragments dating to the Ramesside period (Gardiner 1941, 65), a yield of 12 *khar* of emmer from six *aurora*/freshly cultivated land gives two *khar* per *aurora*:

- 6 *aurora* × 2,735 m² per *aurora* = 16,410 m²
- 12 New Kingdom *khar* = 917.76 litres
- Emmer yield: 917,760 ml ÷ 16,410 = 55.93 ml – 25 per cent = **grain yield 41.95 ml per m²**

The same text also states that a yield of eight *khar* barley plus 12 *khar* emmer from 40 *aurora* was achieved, but how much land was dedicated to which crop is not stated.

There are more references to barley yield than emmer, and compared to the ancient barley yields this emmer yield is very low. The barley yields do not need to be reduced by 25 per cent because barley does not retain the chaff in the same manner as emmer. One of the (Middle Kingdom) Hekanakhte letters contains a note of barley yield. Taking these figures with some caution due to the problems of translating the actual values noted by Baer (1962, 34–5) and Allen (2002, 151), in letter one (Allen 2002, 14) Hekanakhte states that a yield of 65 *khar* of barley from 13 *aurora* is easy to achieve¹⁴. Sixty-five Middle Kingdom *khar* = 3,101 litres

- 13 *aurora* × 2,735 m² per *aurora* = 35,555 m²
- Actual barley yield 3,101 ÷ 35,555 = **87.21 ml per m²**
- **Expected yield = 7,648 litres on 23,750 m² OR on 33,250 m² – Average = 276.01 ml per m²**

P. Valençay I (Gardiner 1951) is a New Kingdom letter of complaint about taxes sent from the Major of Elephantine to the chief tax-master. In it he states that on four *aurora* (of flooded land at Edfu) he had 40 *khar* of barley cultivated – 10 *khar* (160 *hekat*) per *aurora* yield.

- 4 *aurora* = 10,940 m²
- 40 New Kingdom *khar* = 3,059 litres
- **Barley yield = 279.63 ml per m²**

The average barley yield is therefore between 87.21 ml per m² (actual yield in Hekanakhte letter) and 279.63 per m² (in P. Valençay I), with the ideal expected yield being around 276 ml per m², the average being 183.5 ml per m² (the variations no doubt reflecting the fluctuations caused by different Nile flood levels year to year). This is considerably higher than the emmer

yield of the Ramesside document. The problem with relying on such a small number of texts is obvious; to gain a reliable picture of yields a far greater number of texts for a broader time-span is needed. One way to rectify this issue is to look at the ratios between the different barley and wheat yields of more recent Egyptian crops.

In his study of rations, Miller presented data for both wheat and barley during the early twentieth century (1920–39) prior to the construction of the Aswan Dam (Miller 1991, 262–3). These statistics are not for emmer wheat and are from carefully managed irrigated soils, but the relative yields are useful. Looking at the average yield between 1920–39 for barley (299.08 ml per m²) and (non-emmer/free-threshing) wheat (241.32 ml per m²) (Miller 1991, Table 2), it is clear that wheat has a 19.31 per cent lower yield. If average ancient barley yields were 183.5 ml per m², **emmer can be calculated at 148 ml per m².**

The annual requirement is 358,065 kg/486,968.4 litres

- Estimated emmer yield is 148 ml per m²
- $486,968,400 \text{ ml} \div 148 = 3,290,327 \text{ m}^2$ (329 hectares)
- $3,290,327 \text{ m}^2 \div 2,735 = 1,203 \text{ aurora annually}$

It seems reasonable to assume that the grain being received in the Heit el-Ghurab town is actually the tax-grain. So therefore, what area of land would have been cultivated in order to pay those taxes? The issue of taxation levels is complex, and there are many difficulties with translations; determining the difference between rent payments, tax payments and tax assessments is confusing, and very few texts actually state the areas of land. Baer (1962) proposed that 10 per cent of the crop was due as tax (based on assessments of barley), which would mean that the total land cultivated in order to produce 486,968.4 litres (358,065 kg) in tax payments annually would be **3,290 hectares** (12,030 *aurora*).

Grain supplies – labour requirements

Just one ancient Egyptian text provides any information on labour inputs:

P. Bologna 1086 (New Kingdom) records that one man could produce 200 *khar* (sacks) in one year (Wolf 1930).

- Annual 10 per cent tax requirement is 486,968.4 litres, total cultivated = 4,869,684 litres
- Each sack = 25 per cent chaff so the total sack volume has to be $6,492,912 \text{ litres} \div 76.48 \text{ litres per } khar = 84,897 \text{ New Kingdom } khar$ (sacks) per year
- $84,897 khar \div 200 = 425 \text{ farmers working to supply the Heit el-Ghurab barracks}$

Conversely, based on labour requirements in 1801, one *feddan* (0.42 hectare) of wheat required 15 man-days (Baer 1962).

- Annual land cultivated is 3,290 hectares/7,833 *feddan*
- The labour requirement is 117,495 man days – 322 farmers

Once again, working on an average – the labour input would be around 374 farmers.

Storage facilities required

Kemp's (1986) article focussed on the issue of calculating how many people the granaries within Middle Kingdom towns (Kahun and Second Cataract forts) could provide for. In this study the issue is approached from the opposite side of the picture – how much storage was required to keep the town at Heit el-Ghurab fed for the year?

The assumption is that the Heit el-Ghurab granary contents were destined for human consumption (because most of the animals were raised elsewhere (Moens and Wetterstrom 1988; Redding 2013)). One further critical factor affecting the capacity is the 'cleanness' of the grain but, as noted above, the archaeobotanical data seems to indicate that the grain arrived at Heit el-Ghurab already pounded and cleaned. The site of Heit el-Ghurab includes a major complex known as the Royal Administrative Building (R.A.B.), consisting of a series of large circular granaries (for overview, see Murray 2011). The excavators calculated that the height of each granary was at least 1.6 m, and that the diameter of the granaries was an average of 2.6 m (Sadaranghani, unpublished AERA internal report).

- 486,968.4 litres of cleaned grain (or 649, 291.2 litres of chaffy grain [25 per cent chaff])
- c. 8,500 litres volume per granary

Thus, 58 granaries to provide for the barracks for one year (or 77 if grain was un-cleaned).

This is a somewhat implausibly large number of granaries. It is not known how many granaries were housed within the R. A. B complex in Heit el-Ghurab but, working with the estimates of excavators, there may have been up to around 20 in total (Sadaranghani, unpublished AERA internal report). Given the possibility that the grain in these granaries was already pounded, the stores would have been more vulnerable to insect infestation. Perhaps this facility was for short-term storage of grains processed outside the settlement, implying a need for only a smaller number of granaries, and the need for a constant flow of grain supplies coming into the town.

In summary

If the galleries were occupied 365 days in a year by 1,440 active young men:

- Average individual requirement 3,040 kcal/day
- Each individual required 619.26 g of emmer daily

- Annual requirement for the town is 325,477.8 kg /486,968.4 litres of emmer per year
- Which would be equal to 211 F2c large *bedja* loaves required for the town on a daily basis
- Two bakeries with ten people working
- A workforce of 295–148 to grind the grain depending on five or ten working hours per person
- A constant supply of grain coming into the town for short-term storage
- 12,030 *aurora*/3,290 hectares per year to produce enough grain to pay 10 per cent taxes, providing for the town
- 374 cultivators to work the land

The total workforce to simply grow, grind and bake emmer loaves = 533–680 people. That is a ratio of one worker per every two inhabitants of the galleries. If all variables are taken into consideration (fuel/water collection and delivery to the bakeries, pre-grinding, grain pounding, grain transport, delivery of loaves to the inhabitants, administration of the supplies, etc.), it seems plausible to suggest that there may have been a 1:1 ratio of food supply workers to gallery inhabitants.

The values produced using this methodology can very easily be adjusted to reflect any number of additional variables. Within the current model some stages are more tentative than others, but as more work is done, these can be revised and the model adjusted to reflect more stable and reliable data. The calculation for the figures arrived at can very easily be re-run based on small tweaks in data. For example, if the activity factor is lowered from 1.9 (person engaged in very heavy manual labour all day) to 1.7 (person engaged in manual labour but not all day), the calculations are as follows:-

- Average calories per man = **2,719.7**
- 55 per cent from carbohydrate = **1,496 cal**
 - $1,496 \div 4 \text{ cal per g carbohydrate} = \text{requirement of } 374 \text{ g carbohydrate per day}$
- $374\text{g carbohydrate} \div 0.675 \text{ (g carb per g emmer)} = 554 \text{ g of emmer required per man per day}$
- Loaves and bakeries:-
 - F2a loaves ($374\text{g carbohydrate requirement} \div 88.64 \text{ g carbohydrate per loaf}$) = **4.22 per man**
 - $4.22 \text{ loaves} \times 1,440 \text{ men} = 6,077 \text{ small } \textit{bedja} \text{ required per day}$
 - $(6,077 \div 24 \text{ loaves per batch}) \div \text{four batches per day} = 64 \text{ bakeries (320 bakers)}$
 - F2b loaves ($590.44\text{g carbohydrate per loaf} \div 374\text{g requirement}$) = each loaf feeds **1.6 men**

- $1,440 \text{ men} \div 1.6 \text{ men per loaf} = 900 \text{ medium } \textit{bedja} \text{ required per day}$
- $(900 \div 24) \div \text{four} = \text{ten bakeries (50 bakers)}$
 - F2c loaves $(2,851.63 \text{ g carbohydrate} \div 374 \text{ g requirement}) = \text{each loaf feeds 7.6 men}$
- $1,440 \text{ men} \div 7.6 \text{ men per loaf} = 190 \text{ large } \textit{bedja} \text{ required per day}$
- $(190 \div 24) \div 4 = 2 \text{ bakeries (10 bakers)}$
- $554 \text{ g emmer per man per day (1,440 men)} = 797.76 \text{ kg per day for galleries}$
 - $797.76 \div 10 \text{ per cent losses} = 877.54 \text{ kg emmer per day requirement}$
- $877.54 \text{ kg emmer} \times 1.5 \text{ hours work per kg} = 1,317 \text{ working hours to grind flour}$
 - $1,317 \div 5 \text{ hours per day} = 264 \text{ workers grinding}$
 - OR $1,317 \div 10 \text{ hours per day} = 132 \text{ workers grinding}$
- $877.54 \text{ kg emmer per day requirement for galleries} = 320,302 \text{ kg per year}$
 - $320,302 \text{ kg} \times 1.36 \text{ ml per g emmer} = 435,610.72 \text{ litres per year required}$
- Land and Labour
 - $435,610,720 \text{ ml annually} \div 148 \text{ ml per m}^2 \text{ yield} = 2,943,315.68 \text{ m}^2 \text{ land needed (295 hectares)}$
- $2,943,315.68 \text{ m}^2 \div 2735 \text{ m per aurora} = 1,077 \text{ aurora needed}$
 - $435,610.72 \text{ litres in tax payments at rate of 10 per cent} = 4,356,107 \text{ litres total yield needed}$
- $(4,356,107 \text{ litres} \div 3) \times 4 \text{ (25 per cent chaff)} = 5,808,142.67 \text{ litres total sack volume}$
- $5,808,142.67 \div 76.48 \text{ litres per New Kingdom sack (khar)} = 75,944 \text{ khar}$
- $75,944 \text{ khar} \div 200 \text{ khar per man} = 380 \text{ cultivators to supply galleries}$
 - Or $2,950 \text{ hectares total (to pay 10 per cent taxes)} \div 0.42 \text{ hectares per feddan} = 7024 \text{ feddan}$
- $7,024 \times 15 \text{ man days per feddan} = 105,360 \text{ days}$
- $105,360 \div 365 = 289 \text{ cultivators}$
- $435,610.72 \text{ litres of grain required}$
 - $(435,610.72 \div 3) \times 4 \text{ (25 per cent chaff)} = 580,814 \text{ litres storage required for un-clean grain}$
 - $580,814 \text{ litres} \div 8,500 \text{ litres capacity per HeG silo} = 69 \text{ grain silos required}$

Development of the project

In the future it would be of great value to build more variables into this model. For example, the effects of yeast or malting on the nutritional properties of the bread could be taken into account. It might be possible to make some estimations of how many bread moulds were required, and how many workers/how much clay and water might have been needed to make them. The quantity of fuel required in the bakeries could be calculated, as well as the volume of water needing to be supplied to the bakeries. The numbers of people needed to deliver flour, water, moulds and fuel to the bakeries, and to deliver the bread to the galleries, could also be estimated. It will be important to properly establish whether or not grain pounding did take place within this town in order to more accurately calculate the granary capacity required. And it is equally important to look at beer – the second staple carbohydrate. In addition, more comparisons to textual data are now needed, especially grain tax delivery records, in order to properly evaluate the likely numbers of people involved in cultivating the required quantity of grain.

The function of this basic model is to provide a new methodology and a solid basis from which to build. This outline provides a new starting point from which to address the topics of food supply and demand, food production, and the logistics of provisioning in the ancient world; issues which deserve a great deal of attention.

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Notes

- 1 I am indebted to Richard Redding for our discussions of the logistics provisioning the Heit el-Ghurab settlement. We first presented our joint study in January 2013 at the Bioarchaeology of Egypt Conference in Cairo.
- 2 He stated that the 80 sacks of grain left for seed represented 10 per cent of the grain crop. That 80 sacks did indeed come from the 821 sacks collected, but it was from a total of 1,421 sacks available, making the seeds grain in fact just over 5 per cent of the entire crop Baer (1962: 30–31) and Gardiner (1941: 57–58)
- 3 Simpson gave a translation of 60 units from 2/3 hekat of northern barley, and 70 units from 1 hekat of wheat, implying that the bread units being delivered were trsst loaves. However, according to his own transcriptions, on token 'B' 80 loaves are listed, and on token 'C' 90 loaves are listed. Token 'A' does list 70, but gives no quantity of grain, and tokens 'D' and 'E' do list 60 loaves each. Tokens 'A', 'C' and 'D' are the only three containing the term trsst; leaving some confusion about which tokens Simpson was actually referring to. 'A' is a record of 70 trsst loaves, but with no quantity of grain listed. 'B' is a record of 80 trsst loaves

- and a quantity of 2/3 of barley. 'C' is a record of 90 trsst loaves and 1 unit of wheat. 'D' is slightly damaged but is a record of 60 trsst loaves, possibly from one unit of wheat.
- 4 It should be noted here that the skeletal remains excavated at Heit el-Ghurab by AERA are all intrusive Late Period burials, not relevant to this discussion.
 - 5 Old Kingdom skeletal remains from Giza cemeteries have been recovered from the Fifth dynasty cemeteries above the Heit el-Ghurab settlement, and in the western cemetery adjacent to the Great Pyramid (of Khufu) dating from the Fourth-Sixth dynasties. The published study of these materials looked at spinal deformities, noting the presence of spina bifida in 3.33 per cent of the skeletons examined (Sarry el-Din & el-Banna 2006). Unfortunately, the authors did not give more precise data on the differences between the two cemeteries. Spina bifida can be a result of Folic acid deficiency in pregnant women, resulting from a lack of pulses and dark leafy greens in the diet. A physical impairment such as spina bifida does not significantly impact on the nutritional requirements of the individual, other than the need for a standard 'healthy' diet, but the presence of individuals with the disability may be reflective of a lack of availability of other plant foods in the diet of the mothers of the individuals living in the settlement; and as such is a matter for discussion elsewhere. The only other Old Kingdom skeletal remains from Giza for which osteoarchaeological data is published derive from the later Khentkawes settlement (Kaiser 2009). These individuals were of an entirely different population, and as such the results of Kaisers' analyses are not pertinent to the discussion presented here.
 - 6 The UK Food Standards Authority (FSA) guidelines state that a healthy caloric intake must consist of 50 per cent carbohydrate, a maximum of 35 per cent fat and 55 g of protein (15 per cent) (<http://www.food.gov.uk> – FSA nutrient and food based guidelines for UK institutions; accessed April 2015). United States Department of Agriculture (USDA) dietary guidelines state carbohydrate 45–65 per cent, 20–30 per cent fat, protein 10–35 per cent (<http://www.health.gov> – Dietary guidelines for Americans 2010; accessed April 2015).
 - 7 Noted but not able to be built into this study is the altered availability of nutrients due to grinding. Also the possibility that the emmer was malted or yeast was included in bread (Samuel 1996; 1996a) which would also alter the nutritional qualities of the final bread loaves, as would the process of baking.
 - 8 Note also the discussions Mueller (1975: 255, 259) regarding the question of whether or not these bread rations actually represent real loaves distributed or simply represent units of value.
 - 9 A standard unit of measurement for a 'sack' in ancient Egypt, widely accepted to be 4.78 litres.
 - 10 See note 3 above for problems with the publication of these dockets.
 - 11 My calculations based on the mould making experiments in which they used a conical form of 20 cm long and 5 cm diameter. See Nicholson (1989: 243).
 - 12 According to the images provided in the publication.
 - 13 Spalinger (1986) gives a lengthy discussion of the texts, but it is clearly apparent that they anticipated this 10 per cent wastage.
 - 14 A problem arises with the translation of the ideal yield – Allen first translates that 100 khar on 10 aurora (100 hekat per aurora) is what should be expected, but later states that the value of land size given in line 14 should be translated as 14 aurora.

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