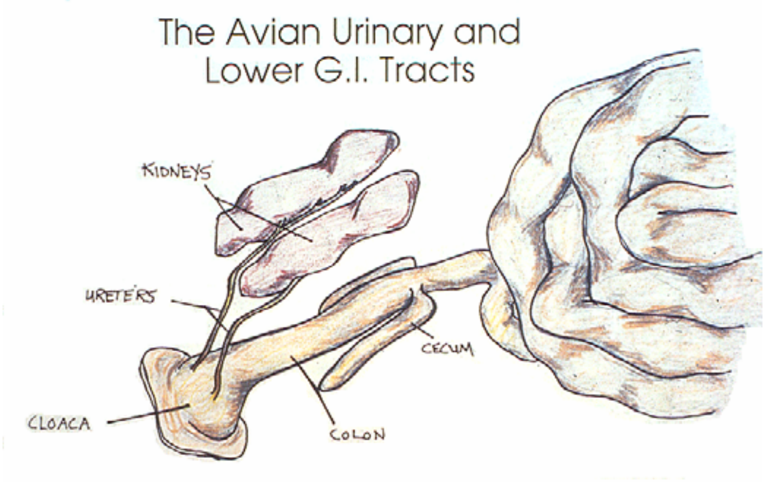
These are some notes focusing on Birds and Reptiles. Much of the overview was taken from the lecture notes of Eldon Braun (2005). Multiple organs are involved in osmoregulation across the diversity of vertebrates (Braun, 2005):

Group	Osmoregulatory Organs
Fish	**Kidneys** **Gills** **Bladder** **Intestine**
Amphibians	**Kidneys** **Gills** **Bladder** **Skin** **Intestine**
Reptiles	**Kidneys** **Salt Glands** **Intestine**
Birds	**Kidneys** **Salt Glands** **Intestines**
Mammals	**Kidneys**

In terms of Osmoregulation and Excretion, Mammals are the unusual group!

Both birds and reptiles excrete excess nitrogen in the form of uric acid, a strategy that conserves water and recycles salts, but how does it work?

Let's focus on birds first. Both the renal and gastrointestinal systems are involved in osmoregulation and ionoregulation.



(Braun 2005)

Figure 1. Anatomy of the avian urinary and lower GI tracts. Braun 2005.

Note that birds do not have urinary bladders(!). The urine descends from the kidneys via the ureters directly into the cloaca. You may see "**uretal urine**" in the literature, this is referring to the urine directly from the kidneys. The osmotic concentration of avian urine reflects the concentrating ability of the avian kidneys and is the value reported from uretal urine.

As we discussed previously, birds can concentrate urine somewhat, typically up to ~2x plasma osmotic concentration. Their abilities are much less than that of mammals in similar habitats:

TABLE 1. Plasma and urine osmolalities and urine to plasma osmolality ratios for a select group of birds subjected to water deprivation[1]

	Osmolality (mOsm/kg H_2O)		
Animal	Plasma	Urine	U/P_{osm}
Emu	337	459	1.4
Turkey	351	492	1.4
Chicken	341	538	1.6
Bobwhite	395	643	1.6
Brown pelican	341	580	1.7
Roadrunner	348	593	1.7
Senegal dove	379	661	1.7
Crested pigeon	370	655	1.8
California quail	338	669	2.0
Gambel's quail	337	669	2.0
Red wattle bird	388	917	2.4
Singing honey eater	384	925	2.4
Galah	388	973	2.5
Ostrich	290	760	2.6
Kookaburra	348	944	2.7
Zebra finch	361	1005	2.8
Savannah sparrow[2]	450	2020	4.5
Savannah sparrow[3]	349	577	1.7

[1]Data from Willoughby and Peaker ('79).
[2]Saltmarsh race.
[3]Goldstein et al. ('90).

TABLE 2. Plasma and urine osmolalities and urine to plasma osmolality ratios for a select group of large mammals that were water deprived[1]

	Osmolality (mOsm/kg H_2O)		
Animal	Plasma	Urine	U/P_{osm}
Zebu	325	1300	4
Hereford	290	1160	4
Buffalo	281	1124	4
Somali donkey	357	1680	4.7
Hartebeest	352	2010	5.7
Eland	313	1881	6
Wildebeest	305	1832	6
Impala	352	2250	6.3
Beduin goat	314	2200	7
Thomson's gazelle	376	2638	7
Merinos	438	3200	7.3
German merino	381	2896	7.6
Camel	400	3200	8
Oryx	387	3100	8
Fat-tailed sheep	387	3100	8
Goat	362	2900	8
Grant's gazelle	348	2789	8
Rock hyrax	397	3180	8
Awassi	389	3230	8.3
Dikdik	372	4100	11

[1]Data from Maloiy et al. ('79).

(Braun 1999)

If kidneys were the end of the waterline, so to speak, birds would produce a weakly concentrated urine. So how do they conserve so much water while ridding themselves of their nitrogenous waste?

First, uric acid has very low solubility in water (0.384 mOsm), so most of it precipitates out as a solid. Crystals of uric acid cannot move well through the renal system (ouch!), so this precipitate is packaged in tiny microspheres (0.5 to 15 um) in the proximal tubule which can remain suspended. To prevent a coagulation of these microspheres, birds use a high concentration of protein in the urine to keep it as a colloidal suspension (microspheres of protein) and the urine flowing (Braun 1999). Bird urine is indeed high in protein concentration. It is believed that this protein is circulating in the plasma and simply filters through the glomerulus with the rest of the urine.

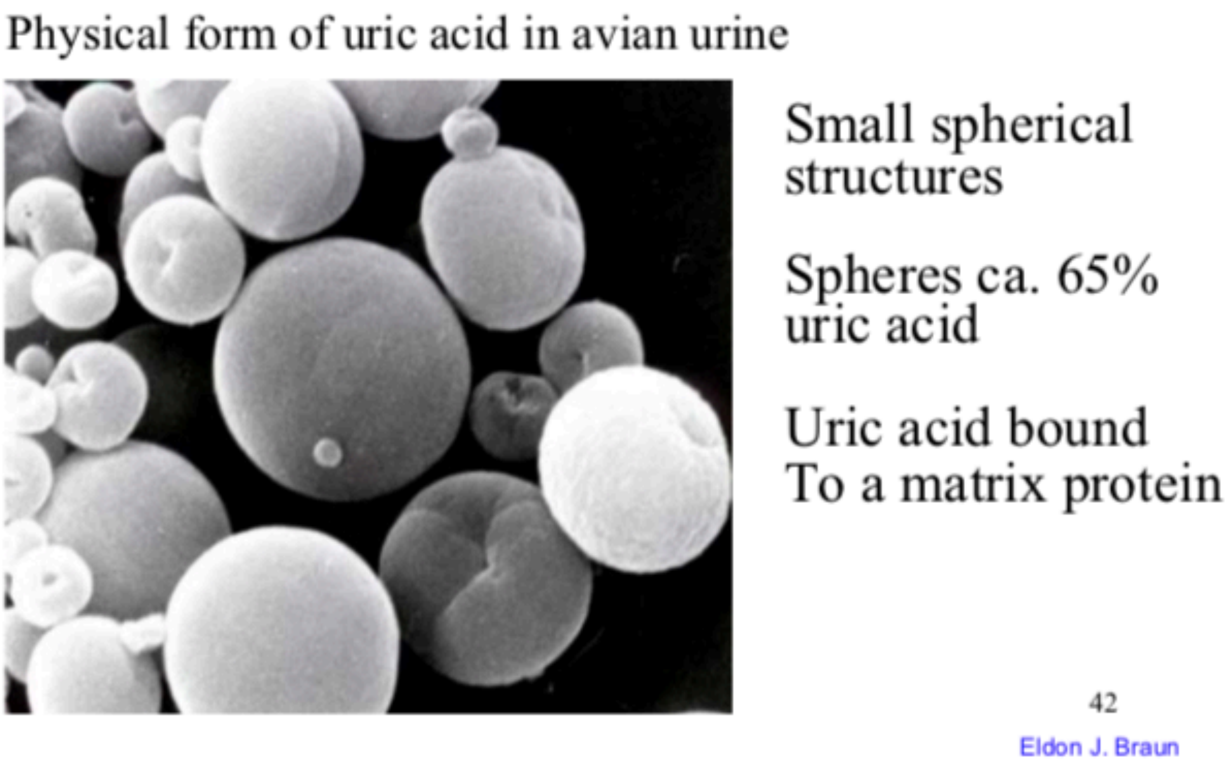


Figure 2. Colloidal structure of uric acid in the avian urine (Braun 2006). It forms microspheres of uric acid and protein precipitates.

Post-renal processing of the urine:

From the cloaca, the urine moves into the large intestine via a process of reverse peristalsis, all the way up to the paired cecae, which are at the top of the large intestine (see figure 1). Recall that the cecum is where fermentation occurs in hind-gut fermentors and contains a lot of microbes.

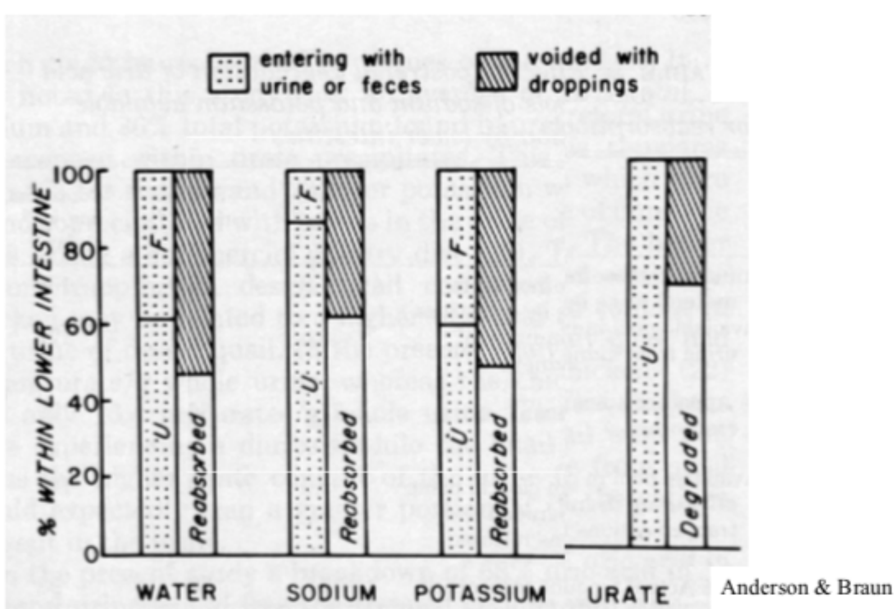


Figure 3. Modification of urine in the lower GI tract of Birds. (Anderson and Braun, 1985)

Within the hindgut, at least three important processes occur (Anderson and Braun 1985, Braun 1999):
(1) 70% of the uric acid and much of the protein is broken down by microbes into VFAs or recycled.
(2) About 77% of the water is resorbed.
(3) About 70-90% of important electrolytes (Na and K ions) are resorbed.

How to model urine in birds?

1. Calculate the amount of uric acid produced from the protein content of food consumed.
2. Reduce the uric acid to 30% of the consumed value, as 70% is broken down by the microbes in the hind gut.
3. Calculate the amount of water to dilute the uric acid to the uretal urine concentration (you can use the Braun 1999 table above).
4. Since 77% of the water is resorbed in the hindgut, reduce the uretal urine water to 23% the value you obtained in step 3.

The uric acid and water that you will have at the end is the cloacal urine, or what will be voided from the cloaca as the white semisolid excrement that birds produce.

Feces can be modeled using the data in Anderson and Braun (1985). They studied desert quail and measured food input and excrement output. They report both water content (75%) and dry matter content of the feces. Note that in birds, urine and feces are voided together.

REPTILES

The excretory system of reptiles is not as well studied as that of birds, so we do not know if all of the mechanisms are all the same, but with what we do know there are many similarities.

Reptiles have no ability to concentrate urine and so the urine concentration will match the plasma concentration of solutes.

Many lizards have bladders (not all) which may serve as a water reservoir. Snakes do not have bladders, and all turtles do.

We will focus on lizards. We do know that the uretal urine enters the cloaca-colonic complex, and that they have a large post-renal absorption of water and electrolytes. Bradshaw (1975, 1986) found that lizards resorbed 90% of the water from the uretal urine. Thus, after calculating the water required to produce the dilute urine, you can take 10% of it for the cloacal urine that is voided.

Minnich and Shoemaker (1972) measured urine and feces water composition in desert lizards, and provide some data that can be used to model urine and feces. If we assume that all of the solid component in urine is uric acid (it's not, but it's OK as a rough approximation), then we can get the uric acid component from the food, convert the moles uric acid to grams, and using the values reported of 0.33ml of water per g of urine (Minnich and Shoemaker 1972), we can calculate the water loss. They found that the feces was composed of 50% water (some guidance is also given in Withers 1992). Then after assuming some small amount for bacteria (5-10%?) the remainder should be indigestible from the diet.

Urine Water loss:

1. Calculate the amount of uric acid produced from the protein content of food consumed.
2. (Strategy 1) Calculate the amount of water to dilute the uric acid to the uretal urine concentration.
    1. Water content in clocal urine is reduced by 90% (Bradshaw studies).

Or

3. (Strategy 2) Convert moles uric acid to grams using MW of uric acid 168.11g/mol
    1. Use the water loss of 0.37ml/g x uric acid (g) = grams of water lost to urine (Minnich and Shoemaker 1972).

Citations:

Anderson, G.L., and Braun, E.J. (1985) Postrenal modification of urine in birds. *Am. J. Physio*l. 248 (Regulatory Integrative Comp. Physiol. 17): R93-R98.

Bradshaw, S.D. (1975) Osmoregulation and pituitary--adrenal function in desert reptiles, *Gen. Comp. Endocrinol.*, 25, 230-248.

Bradshaw, S.D. (1986) *Ecophysiology of Desert Reptiles*. Academic Press, Sydney, pgs. 1- 324.

Braun, E.J. (1999) Integration of organ systems in avian osmoregulation. *Journal of Experimental Zoology*. 283:702-707.

Minnich, J.E., and Shoemaker, V.H. (1972) Water and electrolyte urnover in a field population of the lizard, *Uma scoparia*. *Copeia*, Vol 1972 (4): 650-659.